PROJECT APPRAISAL REPORT (PA

1. PROJECT NO.	2. PAR FOR PERIOD:	3. COUNTRY	4. PAR SERIAL NO.
995-574	Dec. 1974 TO Jan. 1976	Worldwide	

5. PROJECT TITLE

Sulfur Surface Bond Housing

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6. PROJECT DURATION: Began FY 1974 Ends FY 1976	7. DATE LATEST PROP	8. DATE LATEST PIP	9. DATE PRIOR PAR
	N/A	N/A	Dec. 1974

10. U.S. FUNDING	a. Cumulative Obligation Thru Prior FY: $ 190,000	b. Current FY Estimated Budget: $ 55,000	c. Estimated Budget to completion After Current FY: $ 245,000

11. KEY ACTION AGENTS (*Contractor, Participating Agency or Voluntary Agency*)

a. NAME	b. CONTRACT, PASA OR VOL. AG. NO.
Southwest Research Institute, San Antonio, Texas	Contract AID/ta-C-1057

I. NEW ACTIONS PROPOSED AND REQUESTED AS A RESULT OF THIS EVALUATION

A. ACTION (X) USAID	AID/W	HOST	B. LIST OF ACTIONS	C. PROPOSED ACTION COMPLETION DATE
	X		Final evaluation after completion of project and receipt of final report.	12/31/76

D. REPLANNING REQUIRES

REVISED OR NEW: ☐ PROP ☐ PIP ☐ PRO AG ☐ PIO/T ☐ PIO/C ☐ PIO/P

E. DATE OF MISSION REVIEW

PROJECT MANAGER: TYPED NAME, SIGNED INITIALS AND DATE	MISSION DIRECTOR: TYPED NAME, SIGNED INITIALS AND DATE
Merrill W. Con	Office Director, H. A. Arnold

Worldwide Technical Assistance and Research

FY 1975/76 Technical Assistance Bureau Program Submission
Project and Budget Analysis Matrix

KPA 21 Reducing Public Investment Costs

Project No. 995-574 Title Sulphur Surface Bond Housing

Contract/XXXX No. AID/ta-C-1057 Name Southwest Research Institute

Project Officer Merrill Conitz Extension 28937

Major Country/Countries
Colombia, Botswana, Tanzania

Obligation: Initial FY 1974 Final FY 1976

Service : Start FY 1974 End FY 1977

RAC/XXXXX Status: Project approved thru FY 1977
Section 211(d): Project approved thru FY 19
Evaluation Scheduled March 1977 A
Month Year Type

On-Going Only

Narrative	Objectively Verifiable Indicators	
B1 PURPOSE: To compare sulphur surface bond techniques with concrete-base surface bond and conventional mortar techniques of house wall construction in three developing countries in the following respects: degree of skill required, cost, builder and buyer acceptability, durability, wall strength, and suitability of local materials. Also, to evaluate applicability of sulphur combined with other wall materials such as mud blocks.	B2 End of Project Status: 1. Basis established for decisions on use of sulphur bonding technique in house construction.	B3 Progress to Date: Test houses constructed, data being collected and technical assistance in construction of forty sulphur bonded houses requested by Instituto Credito de Territorial.
C1 OUTPUTS: 1. New knowledge related to use of sulphur bonding as cost effective and socially acceptable technique for house construction in LDCs. 2. Familiarization of LDC housing officials and builders with use of sulphur bonding in house construction.	C2 Output Indicators: 1. Comprehensive reports on cost effectiveness of sulphur bonding technique compared with other techniques for test houses constructed in three LDCs.	C3 Progress to Date: 1. Four surface bonded houses constructed in Colombia. 2. Report entitled "Techniques for Sulfur Surface Bonding for Low Cost Housing" completed. 3. African phase underway with demonstration projects completed in Botswana and Tanzania.

D1 INPUTS:
1. Financial support and technical monitoring by AID (TA/OST) assisted by NBS. Technical implementation by SwRI.
2. Contribution of local counterparts in country coordination; identification of local participants; site identification and selection; provision of labor and materials for test houses; economic, social, and physical data collection; testing of structures and material in local laboratories; and assistance in disseminating results.

D2 Budget Summary (in thousands of dollars)

All Prior Year	(1) Personnel Dollars	(2) Personnel TM	(3) Commodities	(4) Other Costs	(5) Total	(6)* Expenditures	(7) June 30 Pipeline	(8) Funding Period Month	(8) Funding Period Year
1. Thru FY 1974	75	12	5		80	80	--	Dec. 73	June 1975
2. Actual FY 1975	100	15	10		110	25	85	Sept. 74	April 1976
3. Estimated FY 1976	53	7	2		55	90	50	Dec. 75	March 1977
4. Estimated I.Q.					-	20	30		
5. Proposed FY 1977					-	30			
6. All Other					-				
7. Total Cost of Project					245	245			

*Expenditures are to be computed on an accrual basis

III. Standard/Key Questions

A. Project Inputs

1. Are key inputs being supplied according to plan by: (a) AID, (b) action agent, (c) cooperating countries, (d) multilateral organizations, and/or (e) other donors?

/XX/ YES /_/ NO If no, explain.

2. Are assumptions regarding the supply of inputs still valid?

/XX/ YES /_/ NO If no, explain.

3. Rate performance of action agent(s) against plan:

/_/ Outstanding /XX/ Satisfactory /_/ Unsatisfactory

Comment on key factors determining rating.

B. Transformation of Inputs into Outputs

4. Given the answers above, i.e., progress to date in supplying inputs, changes in assumptions, etc., is the management hypothesis that the totality of the resources applied to the project will be sufficient to produce the predetermined outputs by the specified target dates still valid?

/X/ YES /_/ NO If no, explain.

5. Is the approach or course of action originally selected, i.e., project design and/or methodology, still the most appropriate?

/X/ YES /_/ NO If no, what changes need to be made in either inputs, workplans and/or output expectations?

C. Project Outputs

6. List the output indicators, their planned targets, and the actual performance achieved for each during the period under review. 7/ See Matrix

a. Was actual performance less than planned target?

/_/ YES /X/ NO If no, explain.

7/ For this and any other questions or statements, if adequate, reference may be made to the project matrix, issues narrative, action agent's report, worksheets, or any other attached or readily available documentation.

What changes, if any, are necessary in outputs, output indicators, target dates, and assumptions?

Additional research on the application of sulfur to lower cost materials, such as mud blocks, needed.

Are they reflected in attached matrix?

[X] YES [ ] NO

c. Do action agent's reports provide adequate progress data for monitoring and analysis?

[X] YES [ ] NO If no, what action will be taken to correct situation?

NOTE: At the discretion of the Office Director, the following questions may be omitted in an informal (Option A)evaluation.

D. Project Purpose

7. Give statement of purpose as currently conceived if different from attached matrix.

a. Is it same as in PROP?

[ ] YES [ ] NO

b. Same or consistent with contract/PASA/grant?

[ ] YES [ ] NO

8. List conditions which will exist when above purpose is achieved--if different from those in attached matrix--or at any other particular point in project implementation, and cite or refer to evidence to date of progress towards conditions (EOPS).

9. Are critical assumptions for achieving purpose still valid?

[ ] YES [ ] NO If no, explain.

10. Is the development hypothesis that the aggregate production of outputs will lead to the creation of a set of conditions at the end of project, i.e., achievement of project purpose, still valid?

[ ] YES [ ] NO

Is the rationale as stated in the PROP still sound.

[ ] YES [ ] NO

If answer to either question above is negative, what changes are necessary (e.g., redesign, extend or terminate project, increase amount of inputs or production rate, change action agent)?

SULFUR SURFACE BOND HOUSING

Issues Narrative

This project was reviewed informally on January 29 and 30 by John Colby, SER/H and Merrill Conitz TA/OST at San Antonio. The environmental aspects were further reviewed in Washington on February 11, with Wendell Anderson, SER/ENGR; Noel Raufaste and Geoffrey Frohnsdorff of NBS, David Black of SwRI, Jan Platou and Harold Fike of the Sulfur Institute and Henry Arnold and Merrill Conitz of TA/OST.

The two principal issues discussed were on the optimum combination of materials in wall construction for maximum economic benefit and the potential environmental hazards of sulfur bonded housing.

At the time of the visit to San Antonio, SwRI had constructed four wall panels of mud blocks in addition to the concrete block panels that had been constructed earlier. Two of the test panels were coated with burlap in different configurations prior to the application of sulfur, one was left uncoated, and one was coated with latex to compare the bonding of latex to mud with that of sulfur.

In order for the sulfur technique to be appropriate for housing that will benefit the very poorest segment of the population, it is necessary to find ways of combining it with wall materials that have practically no cost. Mud, mud blocks, thatch, fiber mats, woven bamboo are all examples of wall materials that have been considered as possible candidates for sulfur applications. At this time, mud block walls seem to offer the greatest potential and these are being investigated.

While molten sulfur bonds readily to most any material, ordinary mud blocks lack the cohesive strength to retain a sulfur coating. The hardened sulfur tends to separate in sheets taking the outer surface of the block with it. To overcome this problem, SwRI has experimented with a covering of burlap over the blocks prior to the application of sulfur. While this overcomes the problem of sulfur flaking off in sheets there are some questions remaining as to its appropriateness such as the cost and availability of burlap and the possibility of its eventual deterioration. In view of these uncertainties, it was felt that some alternatives should be investigated. The possible alternatives in the application of sulfur to mud blocks which were identified during the visit were as follows:

(1) burlap sheets held between courses (already constructed)

(2) burlap sheets nailed on (already constructed)

(3) burlap imbedded during formation of the blocks

(4) fibers imbedded during formation of the blocks

(5) blocks painted with reinforced sulfur before stacking

(6) blocks with at least one (outer) surface impregnated by dipping

(7) conventional blocks but with fibers (grass, sisal, etc.) placed in joints during construction of walls

(8) blocks with intermediate surface treatment such as asphalt or latex

SwRI will begin testing the most promising of these alternatives for possible use during the African phase.

The question of the effect of aging on sulfur coatings has been raised. SwRI agreed to conduct strength tests on blocks cut from the sulfur bonded building on their campus which was constructed more than twelve years ago.

The chief economic advantage of applying sulfur on walls made of conventional concrete block is in the savings of both cost and time in the use of sulfur bonded lintels and perimeter beams as replacements for reinforced concrete.

It is, however, difficult to draw up specifications for the construction of such beams and lintels given the probability of variations in block strength, sulfur formulation and thickness of application. It was agreed that on site performance testing was probably the most reliable. SwRI will draw up specifications for the construction of beams and lintels as well as specifications for performance testing.

The environmental question was raised by Robert Snell, SER/ENGR in a memo dated January 19, 1976. Mr. Snell expressed concern about the levels of SO_2 and SO_3 in a sulfur bonded house that accidentally cought on fire. This question had already been covered in an article by John Dale in the SwRI report entitled "Techniques for Sulfur Surface Bonding for Low Cost Housing." SwRI, however, agreed to provide additional information to satisfy this concern and any others that might be raised in the future. Two reports from the National Safety Council are attached. David Black of SwRI further agreed to discuss these findings with SER/ENGR personnel in Washington on February 11. Unfortunately neither Mr. Snell nor Mr. Vogel were able to attend the February 11 meeting, but Mr. Anderson capably represented their office. Noel Raufaste and Geoffrey Frohnsdorff of NBS also agreed to review the material and attend the meeting as disinterested experts. The Office of Toxic Substances of EPA was invited to attend but declined on the basis that they had no one who was an authority on sulfur and did not feel that it was a potentially harmful substance. Those present felt that the material provided by SwRI adequately answered the concerns expressed and that there should be no problem in proceeding with the project. Mr. Anderson stated that had Mr. Snell seen the earlier report prepared by SwRI, he would probably not have felt it

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necessary to raise this issue. Nevertheless it was useful to have the question reviewed by a capable panel. David Black offered to conduct soil tests in the vicinity of the building at SwRI for the presence of sulfuric acid.

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GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : See Distribution DATE: 3/2/76

FROM : TA/OST, Merri[illegible]

SUBJECT: Report of Travel to Southwest Research Institute, San Antonio, Texas

The purpose of this trip was to review the Sulfur Bonding Project and observe research progress that has taken place since the completion of the Colombia phase. The trip also provided an opportunity to discuss progress in the Substitute Materials small research project which was recently started by SwRI. John Colby, SER/H accompanied me on this trip. John has an extensive background in developing country housing and contributed substantially to the review.

The principal issues in the sulfur project were of finding an optimum combination of sulfur and wall material and potential environmental hazards. Since the Colombia phase, during which sulfur was used successfully to bond conventional concrete blocks, an attempt has been made to find ways of applying the sulfur to cheaper basic materials such as mud blocks. It is felt that the full economic benefit potential of the sulfur technique can only be realized when very cheap materials, such as mud blocks, are used as the basic construction material. Experimental work with sulfur and mud blocks was examined and suggestions made for additional tests. A more detailed discussion is found in the attached PAR.

Shortly before our trip to San Antonio, SER/ENGR raised the question of possible harmful effects of sulfur on the inhabitants of houses bonded by this technique. While the report of the Colombia phase covers this issue, SwRI agreed to provide more information on the environmental question. This material was also reviewed during the visit. David Black agreed to come to Washington the following week to present this material to SER/ENGR.

The second day of the visit coincided with a visit to SwRI by three United Nations housing development experts. The three included Dr. E. Paul Mwaluko, Director of the U.N. Center for Housing, Building and Planning, his Deputy, Mr. Lev Lyubimov, and Technical Advisor, Bruce Hyland. Dr. Mwaluko presented a review of problems to be discussed at the forthcoming Habitat conference and his associates discussed various aspects of the work of the center.

5010-110

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The small research project in Substitute Materials is proceeding on schedule. Mr. John Funnell, Project Manager, has collected an impressive amount of background material and has selected representative countries whose resources and imports will be examined in detail for possible substitution opportunities.

Distribution:

SER/ENGR, John Rixse
SER/H, John Colby
TA/OST, Henry Arnold

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SOUTHWEST RESEARCH INSTITUTE

8500 CULEBRA ROAD • POST OFFICE DRAWER 28510 • SAN ANTONIO, TEXAS 78284

28 January 1976

Office of Science & Technology
(TA/OST)
Agency for International Development
Department of State
Washington, D.C. 20523

Attention: Mr. Merrill W. Conitz

Subject: Contract No. AID/ta-C-1057
SwRI Project No. 11-3853

Dear Merrill:

The question has been raised concerning the generation and buildup of sulfur trioxide and sulfur dioxide as a potential health hazard when the sulfur coated wall houses are occupied. In research work done by D.L. Chamberlain, Jr. at Stanford Research Institute for The Sulphur Institute in 1962 it was determined that "Accelerated weathering experiments on pure sulfur surfaces agreed, qualitatively, with outdoor weathering experiments, and indicated that the surface loss from sulfur films by oxidative processes would be negligible under ambient natural conditions. Among the components of an accelerated environment, temperature was the most important, and losses due to sublimation began to be important at about 80-90°C (175-195°F)." (The maximum block body temperature in the hot Southwest is 140°F.) They also found that the influence of UV light, ozone, and water vapor of much less importance than the temperature effect.

Table IV shows the results of several experiments conducted at various temperatures. No measurable SO_2 or H_2S was determined using coulometric titration. The SO_2 values that were calculated from the barium sulfate formation are highly unreliable as pointed out by the author since 0.061g of sulfur was sublimed near 100°C (212°F) as opposed to 0.017g of sulfur oxidized. The author states "Further, the observed oxidation probably occurred with the sulfur vapor, rather than by attack of oxidants upon the solid sulfur surface." Even using these data at the room temperature experiments, the

concentration varies from 0 to 0.6 ppm, well below the threshold limit value (maximum acceptable concentration averaged over a normal working day) of 5 ppm recommended by the American Conference of Governmental Industrial Hygienists. In these studies it is specifically mentioned that no SO_3 was ever formed.

Our experience with the sulfur coated building here at the Institute over its 13 year history has never indicated any problem of SO_2 or H_2S generation.

The second question raised was that of ingestion of the sulfur by humans. Sulfur and molasses has long been used as a mild laxative, while sulfur tablets and pills are currently used for certain dermatological problems. Sulfur is also an important element fed to farm animals in salt and mineral blocks.

In the sulfur mining industry, workers routinely work around sulfur relay stations and holding tanks where up to 50 thousand tons of molten sulfur are stored. To our knowledge there has not been any problem from the sulfur or vapors as a health hazard in the 70 odd years the Frash process has been operating.

The specific problem of sulfur containing 2 to 3 percent of dicyclopentadiene plasticizer may be different than that of elemental sulfur, however, it is not expected to be. The fact that such a small quantity of plasticizer is available, plus the fact that dicyclopentadiene is used in perfumes no problem is envisioned. The only way to determine exactly what affect additives would have would be to conduct exhaustive long term studies on this as has been done on elemental sulfur.

Attached are copies of the National Safety Council's Data Sheets 592 and 612, dealing with the handling of molten and solid sulfur respectively. According to the National Safety Council there are no known systemic or chronic effects from elemental sulfur, and no permanent systemic effects from either SO_2 or H_2S.

In summary we envision no problems of any gas generation nor any problem if any of the wall coating is ingested by children.

Sincerely,

Allen C. Ludwig

Allen C. Ludwig
Senior Research Engineer
Process Research & Engineering

ACL:mm

Table IV

ACCELERATED AGING OF SULFUR SURFACES

NOTEBOOK REFERENCE	RELATIVE HUMIDITY[a] (%)	H_2SO_4 FORMED (mg)	SO_2 FORMED, CALCULATED (ppm)	SO_2 FORMED, COULOMETRIC TITRATION (ppm)	H_2S FORMED, COULOMETRIC TITRATION (ppm)	OZONE CONCENTRATION		TEMPERATURE (°C)	AIR FLOW RATE (cc/min)	RADIATION SOURCE	AREA OF SULFUR EXPOSED (in.^{2})	TIME OF RUN (hrs)	WEIGHT LOSS (lbs/ft^2/yr)	PENETRATION (in./yr)	REMARKS
						Entering Reactor (ppm)	Leaving Reactor (ppm)								
4628-31	0	177.6	18.2	--	--	--	--	110-118	775	H400E1	55	20	0.0617	0.00592	20-hr exposures unless otherwise noted
-37	0	179.0	18.5	--	--	15.4	0	110-118	775	H400E1	47	20	0.0727	0.00698	
-55	0	158.1	16.3	--	--	48.7	4.4	110-118	775	H400E1	47	20	0.0642	0.00615	Caustic scrubber efficiency improved by use of glass bead packing
-72	0	185.2	19.2	--	--	47.7	0	110-118	775	H400E1	34	20	0.104	0.00999	Modified reactor design
-58	0	300.0	31.0	--	--	50.5	0	110-118	775	H400E1	47	20	0.122	0.0117	Outer tube of reactor Pyrex instead of quartz
-75	0	458.3	47.4	--	--	59.6	0	110-118	775	H400E1	34	20	0.257	0.0247	Pyrex outer tube - some melting observed
-79	0	270.6	28.0	--	--	50.4	0	110-118	775	H400E1	34	20	0.152	0.0146	
-69	0	123.1	12.7	--	--	41.1	1.6	110-118	775	H400E1	0.65	20	0.272	0.0261	Weight loss = 0.061 g
-70	0	--	--	--	--	0	0	110-118	775	H400E1	0.65	20	--	--	Weight loss = 0.059 g
-33	92	95.0	9.8	--	--	71.0	2.2	110-118	775	H400E1	47	20	0.0386	0.00371	
-41	92	192.0	19.8	--	--	43.5	0	110-118	775	H400E1	47	20	0.078	0.0075	
-43	92	153.5	16.7	--	--	46.3	3.2	110-118	775	H400E1	47	19	0.0622	0.0599	19-hr run
-48	92	13.6	1.4	--	--	0	0	110-118	775	H400E1	47	20	0.01106	0.00106	Without ozone
-49	0	8.5	0.9	--	--	0	0	110-118	775	H400E1	47	20	0.00346	0.000332	Without ozone
-50	0	6.0	0.6	--	--	42.1	45.9	RT	775	--	47	20	0.00244	0.000234	Ozone, no light, room temp. (RT)
-51	92	1.7	0.2	--	--	46.5	47.3	RT	775	none	47	20	0.000406	0.0000391	Ozone, no light, RT
-53	92	0.3	0.1	--	--	0	0	RT	775	H400E1	47	20	0.000122	0.0000117	No ozone or light, RT
-54	0	0	0	--	--	0	0	RT	775	H400E1	47	20	0	0	No ozone or light, RT
-81	0	79.0	8.2	--	--	40.5	27.9	100	775	none	34	20	0.0444	0.00426	No light, heated chamber, smaller area
-82	0	18.1	1.9	--	--	50.7	44.1	45	775	none	34	20	0.0102	0.000977	No light
-83	0	109.5	11.4	--	--	57.0	47.8	110	775	none	34	20	0.0568	0.00545	Some melting of S coating, no light
-84	0	96.8	10.5	--	--	55.2	11.3	90-100	775	H400E1	34	20	0.0544	0.00522	
-85	0	112.2	11.5	--	--	15.7	0	100-105	775	H400E1	34	20	0.0625	0.006	
-86	0	301.9	135	--	--	52.5	0	105	180	H400E1	34	20	0.169	0.0163	Decreased air flow rate
-87	0	116.0	51.7	--	--	0	0	100	180	H400E1	34	20	0.0651	0.00625	No ozone

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HANDLING LIQUID SULFUR

This data sheet was prepared for the Engineering and Research Committee of the Fertilizer Section, National Safety Council, 425 North Michigan Ave., Chicago 60611, and is published by the Council

ELEMENTAL SULFUR, when pure, is a yellow, crystalline solid. Its melting and freezing points lie between 230 F and 246[1] F; they depend on its previous history and on its rate of heating and cooling. At approximately 320 F, there is an abrupt change in the properties of liquid sulfur. Above that temperature, it is too viscous to pump. Below approximately 320 F, it is only moderately viscous.[2] Liquid, molten sulfur is, therefore, normally handled at 270 F to 290 F. At these temperatures it is not corrosive to steel or aluminum[3,4] except in the presence of trapped water or acid.

2. Sulfur is not soluble in water, but is moderately soluble in many other liquids.[5] Other properties of liquid sulfur are given in Table I.

Uses

3. Along with salt, limestone, and fuels such as coal and petroleum, sulfur is often considered to be one of the four basic raw materials of chemical industry (Fig. 1). Eighty-five per cent (approximately, in 1965) of the elemental sulfur consumed in this country is burned to sulfur dioxide for conversion to sulfuric acid. Users requiring solid sulfur account for less than ten per cent of the elemental sulfur consumed. Seventy-five per cent of the elemental sulfur consumed in the U.S. is produced by the Frasch process, and the rest is recovered from hydrogen sulfide.[11,12]

4. About ninety per cent of the elemental sulfur used in this country is shipped in the liquid state. There are numerous economic and practical advantages to producers and to consumers in shipping sulfur as a liquid rather than as a solid. Not the least of these is the elimination of dust explosions. Although some liquid sulfur was shipped by rail as early as 1946, the shift to liquid shipments was slow until about 1955. Since then, the development of barges and ships for liquid sulfur and the establishment of distribution terminals in the major consuming areas have revolutionized the transportation of sulfur.[13,14,15]

Containers

5. Liquid sulfur is shipped in tank trucks, railway tank cars, tank barges, and tank ships. Tanks are commonly made of steel, which does

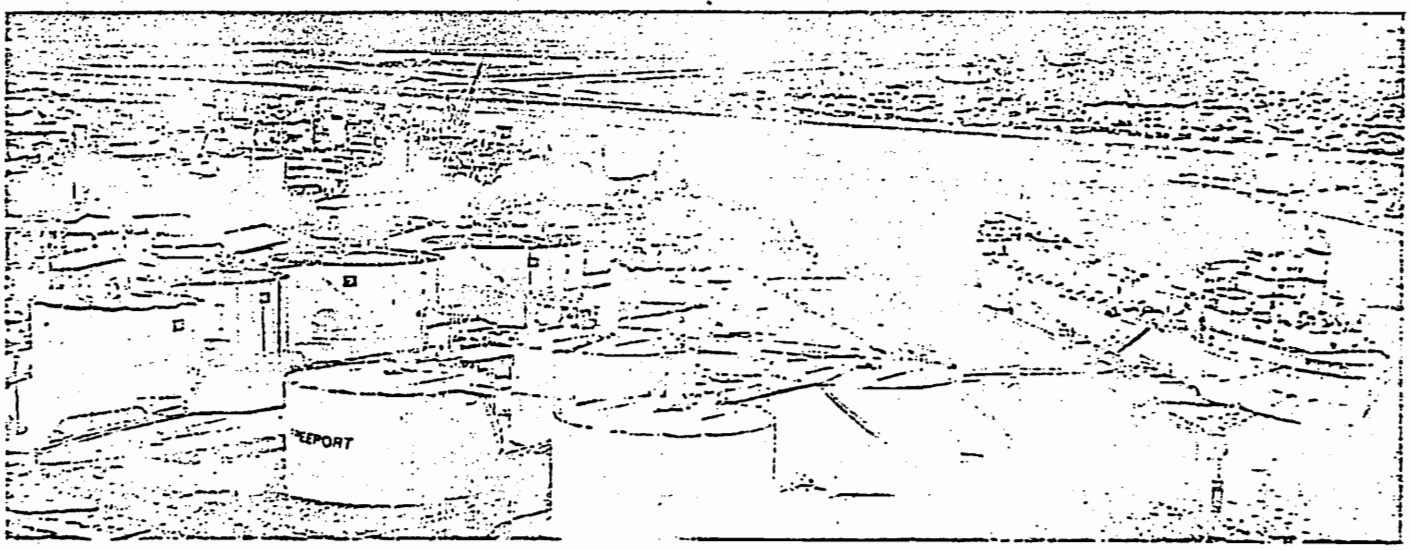

Fig. 1. The demand for sulfur necessitates large facilities such as the 24,000-ton *Louisiana Brimstone*, shown docked at a 90,000-ton capacity terminal. Hazards of storing and transporting liquid sulfur are reduced by venting, which prevents accumulation of toxic and flammable hydrogen sulfide.

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building.

Personnel hazards

10. Sulfur dust is capable of irritating the inner surfaces of the eyelids. It may irritate the mucous membranes of the respiratory passages. There is no evidence that systemic poisoning results from inhalation of sulfur dust.

11. An investigation of workers exposed to appreciable amounts of solid sulfur dust, for a period of seven years, revealed no lung lesions attributed to the inhalation of solid sulfur dust when found on X-ray examinations.[18]

12. In some individuals, sulfur dust has an irritant action on the skin, which may be aggravated by perspiration or moisture.

13. Slides can be a hazard to employees working on bulk piles or in bins of bulk sulfur. Reasonable safe- avoid overhangs and slides. For example, undercutting of sulfur piles must be avoided. Particularly, manual undercutting which is dangerous. The angle of repose of loose bulk sulfur is about 35 deg. Where a man must work in a bin, which is in danger of sliding, he should wear a safety belt with a lifeline fastened securely at the top of the bin, and he should be observed by another employee similarly equipped.

14. The main hazards in handling solid sulfur are fires and dust explosions. Mixtures of sulfur dust and air ignite easily. Ignition temperature is fairly low and the explosive limit range is relatively wide. A small explosion may cause additional dust disturbances which, if ignited, can result in a more severe explosion and ignition of the pile itself. Dusts with 25 per cent of sulfur or more may be almost as 10 per cent or less are nearly nonexplosive.[21]

Handling

15. It is important that dust formation be minimized during the handling of solid sulfur. It is equally important that potential sources of ignition be avoided. The National Fire Protection Association codes are widely used as a basis for good practice in the handling of solid sulfur and should be consulted for detailed advice on these points.[14]

Personal protective equipment

16. Employees working with bulk sulfur should be provided with personal protective equipment. A minimum list includes dust-tight goggles and a safety hat.

17. *Eye protection.* When conditions are dusty enough to cause eye irritation, dust-tight safety goggles should be available to those who may require them. Plastic or rubber frames are recommended because metal bands may cause skin irritation.

18. *Respiratory protection.* Although sulfur dust is non-toxic, dust respirators should be provided for greater employee comfort. A breathing apparatus or masks suitable for use in atmosphere containing sulfur dioxide should be provided for emergency use in case of fire.

19. *Body protection.* Workers whose skin may be sensitive to sulfur dust should protect themselves by wearing collars buttoned, sleeves rolled down, trousers gathered at the ankle, and gloves. A further protective measure may be taken by coating the hands and face with a nonvanishing industrial cream.

20. Use of fire retardant clothing is recommended. Ignition of sulfur impregnated clothing could result in serious burns; therefore, clothing should be kept as free from dust as possible. *Sulfur-impregnated clothing should not be worn.*

Ventilation

21. Totally enclosed motors are recommended for service in sulfur dust. Open induction motors have been used in open locations, but proper cleaning is required. Switches should be waterproof and located as far as possible from dusty areas. It

Properties of Solid Sulfur

Physical state	Crystalline solid
Melting point	230-246 F, depending upon its crystalline form
Color	Yellow (pure) to tan or gray, depending on amount and type of impurity
Explosive limits of dust in air	Minimum about 0.035 oz/cu ft Maximum about 1.4 oz/cu ft
Auto-ignition temperature of dust in air	Dust clouds — 374 F Undispersed dust — 428 F
Corrosivity	Dry — none Wet — slow generation of sulfuric acid which will attack steel
Density	Theoretical — 129 lb/ft^3 Bulk — 75-87 lb/ft^3
Odor	Odorless when pure. May have odor of hydrogen sulfide or hydrocarbon if impure
Specific heat	0.16 Btu/lb (0 F) to 0.19 Btu/lb (200 F)
Vapor pressure	Less than 0.0001 mm, Hg (68 F)
Solubility	Insoluble in water, nonhydroscopic
Reactivity	Burns to form sulfur dioxide. May form explosive mixtures with strongly oxidizing chemicals such as chlorates

meeting the requirements for installation in Class I, Group D locations is satisfactory. (The previous NFPA code of 1959 listed sulfur atmospheres as similar to those in Class II, Group C.)

22. One way to prevent static accumulation is to maintain a relative humidity in the atmosphere of 75 per cent, if that is possible. Blanketing of solid sulfur in transfer operations has been accomplished by the use of water sprays and saturated steam. This practice should be controlled, however, if corrosion problems are to be avoided. Some plants have found that the use of inert gases, such as 12 per cent CO_2 for example, reduce the explosion hazard. The Bureau of Mines found that dust clouds were not ignitable when atmospheric oxygen was reduced to below 10 per cent.[21] The NFPA requires inert gas atmospheres (less than 11 per cent oxygen) in certain types of crushing and grinding machinery.

Fire and explosion hazards

23. Storage bins or buildings should be provided with sprinklers (not brass or bronze). A fine water spray or fog is the most satisfactory extinguishing agent. Hoses and extinguishers with pressure streams should be avoided where solid sulfur is dusty or where it may create a further hazard by raising more dust clouds.

24. Steam can be used for smothering fires in elevator casings and other small enclosures. Carbon dioxide can also be used.

25. Small sulfur fires can be extinguished by carefully smothering with larger amounts of the same sulfur. Sand or dirt can also be used.

26. Because burning sulfur evolves sulfur dioxide, breathing apparatus or gas masks approved for use in acid-gas atmospheres should be made available to workers who should be instructed in their use and limitations. Fumes from unprotected solid sulfur fires should be avoided, if possible, by converging from the upwind side.

27. *To prevent ignition by friction*, hand tools used in handling solid sulfur should be made from nonsparking materials such as mon-

28. [illegible] structed of nonferrous materials, or if ferrous material is used for one part, parts which might touch it should be nonferrous to minimize the chance of sparking.

29. Where large quantities of solid sulfur are used, the installation of a magnetic detector and separator should be considered to remove tramp iron from the sulfur receiving operation.[7]

30. *To prevent ignition by flame*, all solid sulfur should be removed from work areas before repairs are made with welding equipment or the like. If this is not possible, assure a fresh air supply to workers, and provide water to extinguish fires.

31. Gasoline-driven equipment operated in the vicinity should be equipped with spark arrestors and protected muffler and exhaust systems.

32. All open flames, smoking, and matches should be prohibited within enclosures. Heating of sulfur-containing enclosures, if any, should be by indirect means such as steam or preheated air.

Electrical equipment

33. *To prevent ignition by electrical sparks*, metal parts of conveying machinery, hoppers, spouts, power shovels, and other equipment should be grounded in accordance with the NFPA recommendations on static electricity.[13]

34. Recently, certain chemical additions have been found to be effective in suppressing electrostatic changes in solid sulfur. For instance, a solution of 12 per cent disodium phosphate, 3 per cent surface-active agent, remainder water, applied at 1 part per 1000 parts sulfur, gave good results.[7] Another solution found to be effective was ammonia plus a surface-active agent.

35. Solid sulfur is a poor conductor of electricity (resistivity[21] of 10^{17} ohm/cm); when in motion under conditions of low humidity, it can develop sufficient static charges to cause sparking and ignition. On a clear, cold day, throwing a handful of sulfur into the air can generate enough static to ignite the dust cloud that forms.[7]

ment and contact with oxidizing chemicals.

Symptoms of poisoning

37. Solid sulfur is a mild irritant; it has no immediate effect other than irritation of the eyes and no long term effect.[5,6,8,24] Burning sulfur evolves sulfur dioxide; exposure to which results in immediate and severe irritation to the eyes and respiratory system. Neither systemic or chronic effects are known[1,2,6,9]

First aid

38. Persons exposed to sulfur dioxide must be moved to fresh air. Ordinary first aid procedures are adequate for the effects of sulfur itself; however, solid sulfur dust should be removed from the skin after work periods with mild soap and water. Sulfur dust in the eyes is best removed by thorough irrigation with copious quantities of plain water. Inadequate amounts of irrigation fluid may actually increase the irritation.

Treatment of burns

39. Solid sulfur must melt before it burns and the burning sulfur will melt additional material in its immediate vicinity. Skin or clothing burned by contact with liquid sulfur is usually covered with a thin hard coating of solidified sulfur. Liquid sulfur burning over a small area should be covered with a clean, dry dressing. The victim should be treated for shock and removed to a hospital as quickly as possible. DO NOT REMOVE THE SULFUR. Where greater areas are burned, no attempt should be made to remove clothing or sulfur from the affected parts because of the danger of infection. Instead, cover the affected area with a clean sheet or similar material. Application of burn ointment merely complicates the removal of foreign matter from the burned area when treatment begins in the hospital.[6]

Toxicity

40. Solid sulfur is virtually nontoxic. It can be taken internally in fairly large doses without injury. Even when taken intravenously, sulfur is only slightly diuretic, not actively toxic.

41. When sulfur burns in the atmosphere, it forms sulfur dioxide. Sulfur dioxide is irritating to the eyes, nose, throat, and lungs in concentrations greater than 6 to 20 parts per million (ppm). At 150 ppm, irritation is extreme. Concentrations in excess of 400-500 ppm may result in suffocation. The threshold limit value (maximum acceptable concentration averaged over a normal working day) of sulfur dioxide recommended by the American Conference of Governmental Industrial Hygienists is 5 ppm. Exposure to sulfur dioxide has no permanent systemic effect.[1,2,6,9,27]

Medical examinations

42. Special physical examinations are not necessary for employees whose duties will bring them into contact with solid sulfur.

Waste disposal

43. Contaminated solid sulfur is best disposed of by burning if this can be done safely. Sulfur exposed to the weather or buried at moderate depths will slowly generate sulfuric acid. If the resulting acidity is objectionable, the sulfur can be neutralized by mixing with about 3 times its weight of crushed limestone or half that amount of lime before burying it.

ACKNOWLEDGMENT

This data sheet was prepared by the Fertilizer Section of the National Safety Council, 425 N. Michigan Ave., Chicago 60611, and is published by the Council.

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26. W. N. Tuller, *The Sulfur Data Book*, (1954), McGraw Hill Book Co., New York City 10036.

27. *Threshold Limit Values for 1967*, American Conference of Governmental Industrial Hygienists, 1014 Broadway, Cincinnati, Ohio 45202. Also published in the *National Safety News*, (October, 1967). pp. 48-52.

The information and recommendations contained in this publication have been compiled from sources believed to be reliable and to represent the best current opinion on the subject. No warranty, guarantee, or representation is made by the National Safety Council as to the absolute correctness or sufficiency of any representation contained in this and other publications, and the National Safety Council assumes no responsibility in connection therewith; nor can it be assumed that all acceptable safety measures are contained in this (and other publications), or that other or additional measures may not be required under particular or exceptional conditions or circumstances.

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Best Available Document

HANDLING AND STORAGE OF SOLID SULFUR

This data sheet was prepared by the Fertilizer Section of the National Safety Council, 425 N. Michigan Ave., Chicago 60611, and is published by the Council.

SULFUR IS THE CHEMICAL INDUSTRY'S most widely used raw material. In the United States more than 85 per cent of the elemental sulfur consumed is converted to sulfuric acid, where it is used in the production of fertilizers, titanium dioxide, synthetic fibers, a wide variety of chemicals, and in the pickling of iron and steel. This data sheet will focus on the hazards and precautions which should be followed when working with solid sulfur. Handling liquid sulfur is covered in Data sheet No. 592.

Properties

2. Although most of the sulfur converted to acid is handled in the molten (liquid) state, an estimated 10 per cent is still handled as a solid. The physical properties of solid sulfur are listed on page two.

Uses

3. Among the large users of solid sulfur are the pulp and paper, fertilizer, and rayon industries. In the solid, elemental form, it is used as a soil ingredient, in pesticides, and in rubber vulcanizing. It is also crushed and ground for other uses.

Containers

4. Solid bulk sulfur is moved in ships, barges, box cars, hopper cars, gondolas, trucks, and other carriers. Although steel and wood are often used, aluminum is the best all-around material to use because it is nonsparking and resistant to corrosion. Solid sulfur is also bagged in multi-ply paper or, sometimes, burlap bags. Refined or ground sulfur is generally shipped in this way.

Shipping regulations

5. Solid sulfur is not classified as dangerous by the Interstate Commerce Commission. It is, however, classified as a hazardous article by the U.S. Coast Guard, who therefore, requires a number of precautions be taken when solid sulfur is transported by water.[3]

Storage

6. *To prevent dust formation,* enclosures should be constructed with a minimum number of ledges where dust can accumulate. Necessary ledges should be roofed at a steep angle to reduce dust deposits.

7. Scattering of dust where solid sulfur is transferred from one point to another should be avoided. Where feasible, dust-tight housings or hoods with inward air movement should be provided. Mechanical exhaust systems should conform to NFPA standards.[10]

8. Elevators and conveyors should have dust-tight casings and should be equipped with explosion relief vents. Dusting during loading or stockpiling may be alleviated by use of a telescoping spout (preferably aluminum). Long sulfur drops through chutes should be kept at a minimum to reduce dusting.

9. *Other fire precautions* include bins and storage buildings of noncombustible construction. Also, proper ventilation of indoor storage areas is necessary to lessen danger of fire and explosion. As a precaution, it is recommended that explo-

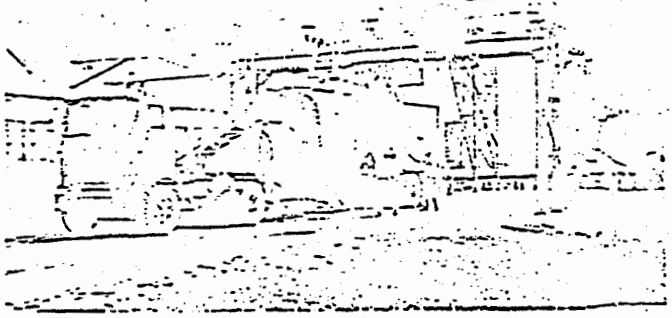


Fig. 2. This special truck carries liquid sulfur one way in the inner tank and carries phosphate rock on the way back in the outer tank.

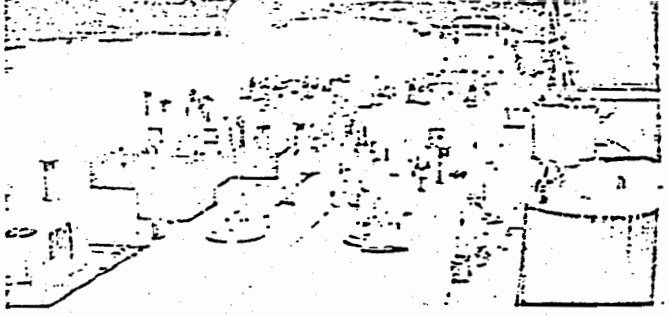


Fig. 3. Barges for liquid sulfur have twin vents for hydrogen sulfide located both fore and aft.

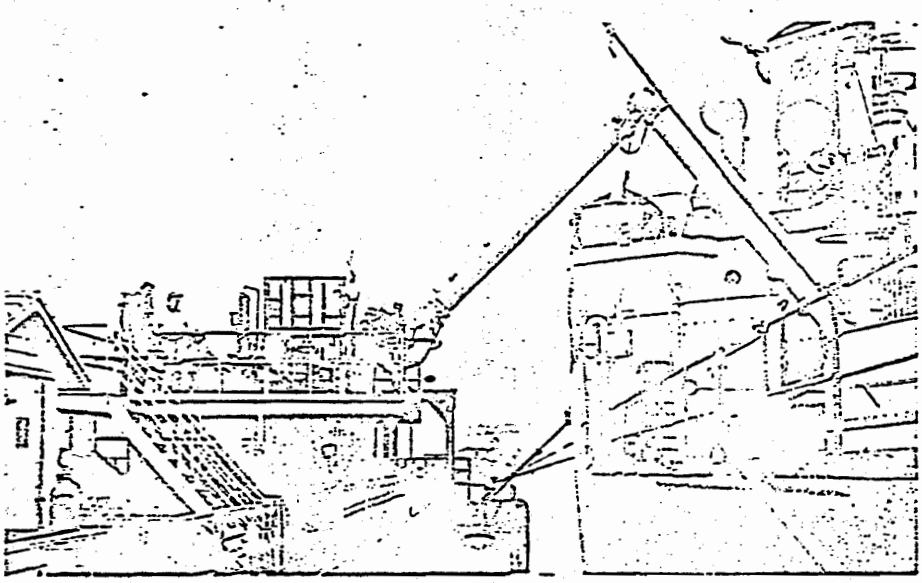


Fig. 4. Liquid sulfur discharges from ships through steam-jacketed pipelines equipped with swivel joints.

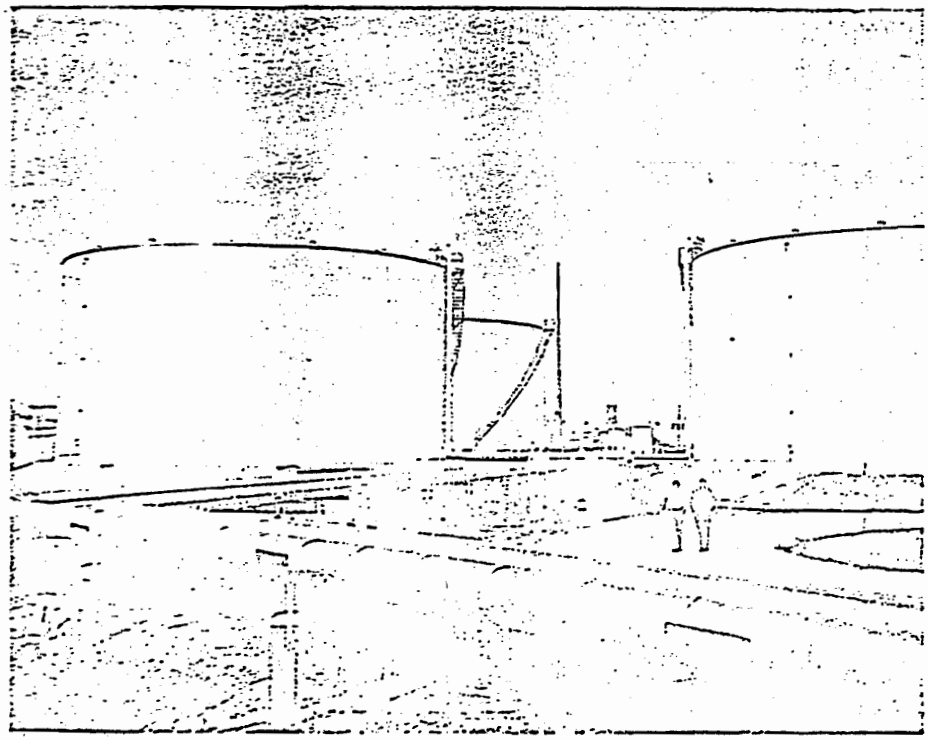


Fig. 5. Liquid sulfur is stored in steam-heated, insulated tanks and pumped through steam-traced, insulated pipes. Vents for hydrogen sulfide are provided around the periphery of the tanks and at the apex of the cone roof or near the center. These tanks are filled and emptied through lines that enter the top of the tank and extend to the bottom.

not corrode if the sulfur is kept hot enough to prevent accumulation of free moisture. Aluminum,, or aluminized steel, is sometimes used for truck tanks because it does not have to be kept hot to avoid corrosion. Shipping tanks are insulated to conserve heat, and are in most cases provided with heating coils.[2,4,16,17,18]

6. Tank trucks may carry up to 22 long tons of liquid sulfur, depending on local regulations. Tanks are usually cylindrical and are not compartmented. They are insulated to minimize heat loss in transit (Fig. 2). Steam coils are not often provided, since trucks are generally used for short hauls. Sulfur is normally discharged by gravity through a steam-jacketed valve into a pump sump or pit.[16,17,18]

7. Railway tank cars range in capacity from 64 to 88 long tons of liquid sulfur. The uncompartmented steel tanks are insulated externally with two to six inches of glass fiber insulation. A few cars have external steam coils. The rest have steam coils inside the tank. Heat is not supplied while tank cars are in transit. Any sulfur which solidifies is remelted before the tank car is unloaded. Sulfur may be discharged by gravity or by air pressure through a steam-jacketed bottom valve or through a steam-jacketed siphon extending up through the dome.[16,17,18,19]

8. The capacity of the present inland waterway barges ranges from 600 to 4,000 long tons (Fig. 3). Barges have oil-fired heaters which circulate heat transfer fluids to keep sulfur hot at all times. Tankers now in service carry as much as 25,000 long tons per voyage. Their steel cargo tanks are usually rectangular and insulated externally. Steam in

pipe coils keeps the cargo tanks at all times. The liquid sulfur is usually discharged from the barges and ships by means of deep well centrifugal pumps which force the liquid through steam-jacketed pipelines equipped with swivel joints for connection to shore (Fig. 4). In some cases, specially designed rubber hose is used to provide a flexible connection.[16,17,18,19]

Shipping regulations

9. Sulfur is not classified by the Interstate Commerce Commission as a dangerous product. Tank cars built or converted for sulfur service conform to various specifications, such as AAR 203-W, ICC 103-W, ICC 111A 100W1, and ICC-111A 100-W-3. Trucks must conform in weight and dimensions, to the legal requirements of the states in which they are used.[16,20]

10. The United States Coast Guard classifies liquid sulfur as a Grade E Liquid and has published regulations governing the transport of liquid sulfur by water.[40]

Storage

11. Liquid sulfur is normally stored in vertical, cylindrical, welded-steel tanks, with externally insulated walls and roof (Fig. 5). Internal or external steam coils are provided to maintain the sulfur at 270 to 290 F. Internal steel surfaces should be above 238 F to prevent the accumulation of solid sulfur, beneath which the steel will corrode in the presence of moisture. For the same reason, the outside of the tank bottom should be kept dry. In designing a tank for liquid sulfur, consideration must be given to sulfur's high density, and to the weight of insulating materials and steam coils. Tanks are provided with conventional ladders, walkways, and guard rails (Fig. 6). Whether or not to provide a tank with a moat to contain the sulfur in case of a leak, or how to separate tanks from other installations should be determined through consultation with fire-insurance carriers and with local regulatory agencies.[16,17,18,19]

12. Ventilation of liquid sulfur tanks is necessary to prevent the accumulation of toxic and explosive quantities of hydrogen sulfide (Fig. 5). Before any tank is filled with sulfur, it must be checked that the tank does have vents. These pipes should be steam jacketed to the very end to prevent plugging with sublimed sulfur. Positive air circulation is achieved by the chimney effect, or less often, by mechanical means. The amount of hydrogen sulfide that will be produced by any given shipment can be reasonably well predicted on the basis of past experience with sulfur from the same source. Of course, reasonable care must be taken that the sulfur does not contact hydrocarbons or other organic matter which would react with it to produce hydrogen sulfide. Also, sulfur with a high carbon content must be suspected of having a high hydrocarbon content. Tests can be made to determine the amount of gas that will evolve.

13. The dielectric constant of sulfur is conducive to the buildup of static electricity. Tanks should be filled from the bottom, or through discharge pipes that extend to the bottom (Fig. 5). Blanketing the vapor space with flue gas or inert gas is unnecessary.[5,16,17,18,29] However, the atmosphere in the vapor space should be checked periodically with an explosion testing meter. Particularly, it should be checked while filling (Fig. 7).

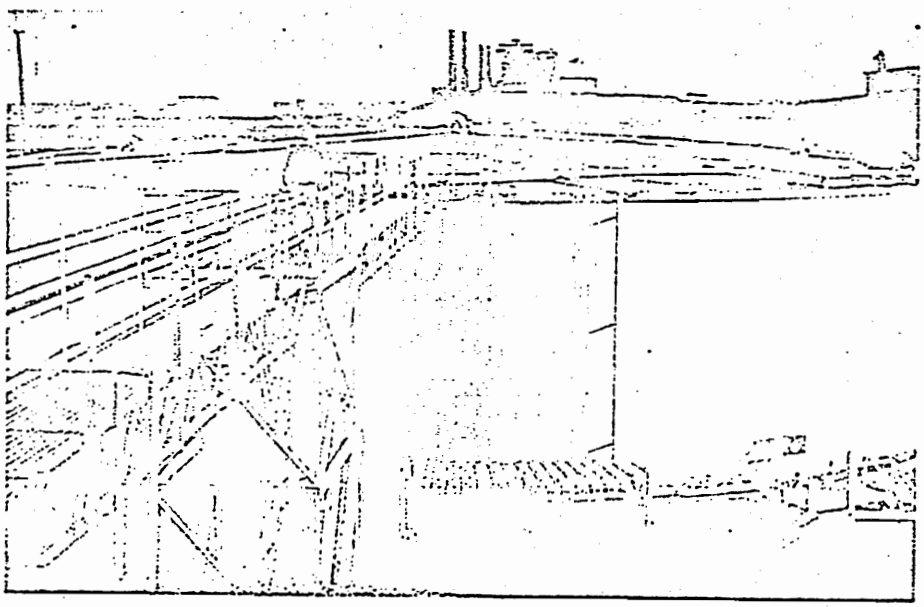
14. Pits are sometimes used to store small quantities of liquid sulfur, or used as pump sumps. For storage of more than 150 long tons, a tank is often more economical. The pits are generally rectangular and are made of concrete or of steel

TABLE I

PROPERTIES OF LIQUID SULFUR*

Specific gravity @ 270 F (Water at 68 F = 1)[6]	1.79
Relative viscosity @ 270 F (Water at 68 F = 1)[2]	9.0
Freezing point (approx.)[1]	238 F
Melting point (approx.)[1]	246 F
Boiling point[7]	832 F
Ignition temperature, in air[5]	478-502 F
Flash point, modified Cleveland open cup[9,10]	335-370 F

*NOTE: At atmospheric pressure.



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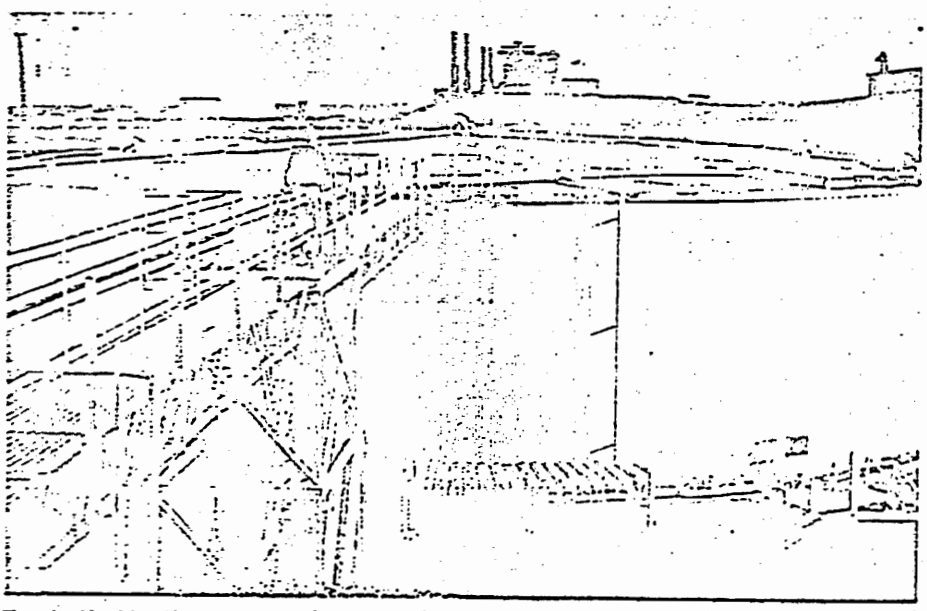


Fig. 6. Liquid sulfur storage tanks are provided with conventional ladders, stairways, walkways,

20

proof cement. Pits are covered w steel, aluminum, or asbestos-cement. Corrosion of steel pit walls and covers in the vapor space is serious in the case of outdoor pits in cold climates, especially those containing recovered sulfur high in hydrogen sulfide. The pits are provided with steam coils located below the minimum sulfur level. Adequate ventilation, guard rails, and warning signs are strongly recommended. Employees should not walk on the covers. Inspection opening left uncovered should be protected with metal mesh gratings.[16,17,18,20]

15. Users of liquid sulfur sometimes wish to provide additional storage by casting sulfur in a large block, called a "vat." This operation is outside the scope of this data sheet. Safe practices in vatting sulfur can be obtained from any of the major sulfur producers.

Hazards

16. Sulfur can be safely, efficiently, and economically handled in its molten form. Safe handling requires recognition of, and adequate protection against, three kinds of danger. First, liquid sulfur is hot. Second, it can burn, and besides the fire hazard, the sulfur dioxide gas that forms is highly irritating. Third, it can sometimes release hydrogen sulfide gas, which is both toxic and flammable. Sulfur vapor, like sulfur dust, is irritating to the inside of the eyelids, but the small amout normally encountered does no permanent damage.[21] Fire hazards will be discussed in a later section.

17. Liquid sulfur splashed in small amounts onto the skin does not penetrate; it quickly freezes into a thin layer. The resulting first degree burn is less serious than that resulting from momentary contact with a hot sulfur pipe or steam pipe at the same temperature (270 to 290 F). If the amount of liquid sulfur is greater and the time of contact is long, deep third-degree burns will result. This most commonly happens when someone gets a bootfull of sulfur.[22]

18. Sulfur dioxide is highly irritating to the eyes, nose, throat, and lungs in concentrations greater than 6 to 20 parts per million (by volume). At 150 ppm, the irritation is almost unbearable. Concentrations in excess of about 500 ppm result in suffocation. The threshold limit value (maximum acceptable concentration averaged over a normal working day) of sulfur dioxide recommended by the American Conference of Governmental Industrial Hygienists is 5 ppm. Exposure to sulfur dioxide has no permanent systemic effect.[23,24,25]

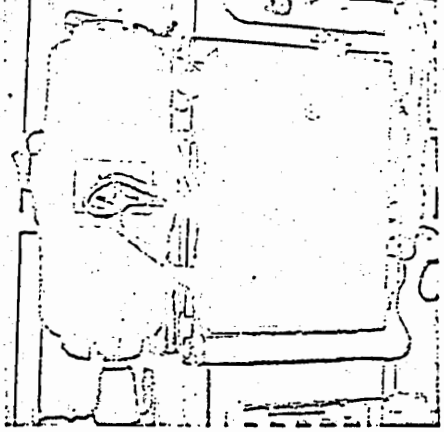


Fig. 7. A gas chromatograph monitors hydrogen and hydrogen sulfide in the atmosphere above liquid sulfur in ship's cargo tanks in order to prevent the formation of explosive mixtures.

19. Hydrogen sulfide gas which may be released from liquid sulfur is extremely toxic to humans. Physiological responses to various concentrations have been reported as follows:[26]

10 ppm

Beginning eye irritation.

50-100 ppm

Slight conjunctivitis and respiratory tract irritation after 1 hour exposure.

100 ppm

Coughing, eye irritation, loss of sense of smell after 2 to 15 minutes. Altered respiration, pain in the eyes, and drowsiness after 15 to 30 minutes, followed by irritation after 1 hour. Several hours exposure results in gradual increase in severity of these symptoms and death may occur within the next 48 hours.

200-300 ppm

Marked conjunctivitis and respiratory tract irritation after 1 hr of exposure.

500-700 ppm

Loss of consciousness and possibly death in ½ to 1 hour.

700-1000 ppm

Rapid unconsciousness, cessation of respiration and death.

1000-2000 ppm

Unconsciousness at once, with early cessation of respiration and death in a few minutes. (Death may occur even if the individual is removed to fresh air at once.)

20. Subjective olfactory responses

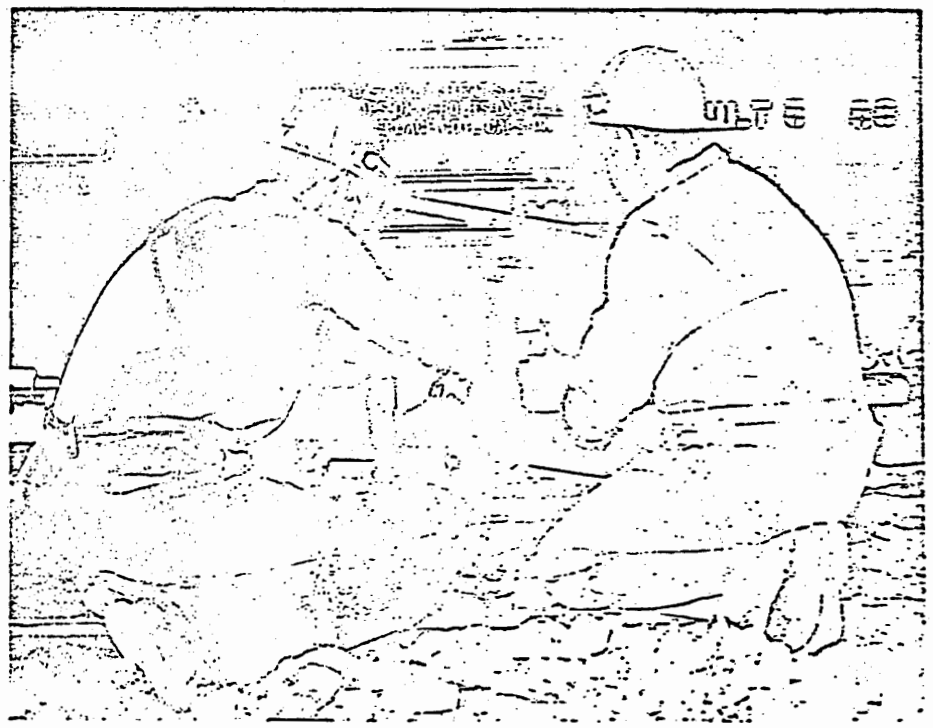


Fig. 8. Steam used to melt frozen sulfur should be saturated and pressure should not exceed 75 psig. The sulfur should not be heated past 290 F.

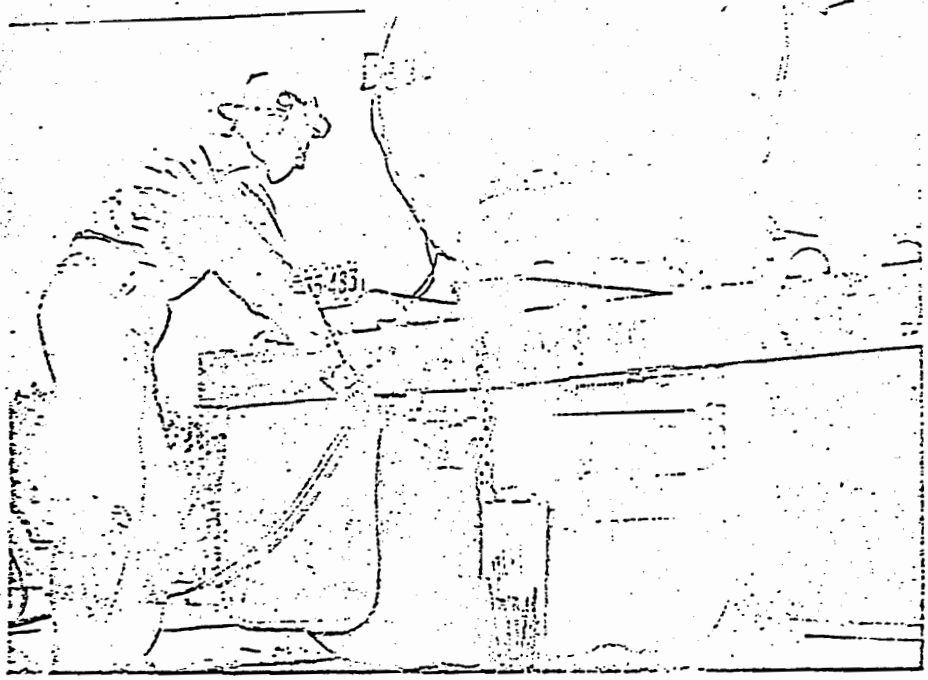


Fig. 9. Tank trucks discharging liquid sulfur should be parked on level ground or ground that slopes slightly downward toward the rear.

to various concentrations of hydrogen sulfide are approximately:[26]

- *0.02 ppm* .... No odor.
- *0.13 ppm* .... Minimal perceptible odor.
- *0.77 ppm* .... Faint but readily perceptible odor.
- *4.6 ppm* .... Easily detectable, moderate odor.
- *27.0 ppm* .... Strong, unpleasant odor, but not intolerable.

However, it is dangerous to rely on odor as a measure of concentration since in higher concentrations, or upon long exposures, hydrogen sulfide paralyzes the sense of smell. (Sulfur dioxide, on the other hand, is so irritating it cannot be endured.)

21. The chief effects of hydrogen sulfide are on the eyes, nose, throat, and lungs. An exposure sufficient to cause unconsciousness may lead to an injurious fall, may be fatal in itself, or, if not fatal, may be followed by bronchial pneumonia or by temporary blindness.[23,24,27,28,29] The threshold limit value (maximum acceptable concentration averaged over a normal working day) of hydrogen sulfide recommended by the American Conference of Government Industrial Hygienists is 10 parts per million.[24]

Handling

22. Transfer of liquid sulfur from trucks, tank cars, barges, or ships to storage facilities should be conducted and supervised by carefully trained employees. A variety of piping, valve, and pump arrangements are used, so detailed instructions should be made available for reference.[16,17,18,30,31,32]

23. Pressure of saturated steam used to melt frozen sulfur should not exceed 75 psig. Regardless of the steam pressure used, the temperature of the sulfur in the container should not exceed 290 F (Fig. 8). Superheated steam should not be used. Pressure of air used to unload sulfur from tank cars should not exceed 30 psig, or whatever lower pressure is stencilled on the car or truck or specified by the shipper. When compressed air is used for unloading, care must be taken to have clean contact surfaces between the dome cover and the ring. Also, bolting must be done in such a manner that the contact surfaces seat effectively around the entire circumference. In this way air is conserved and the dangerous leakage of gas or of liquid sulfur is avoided.

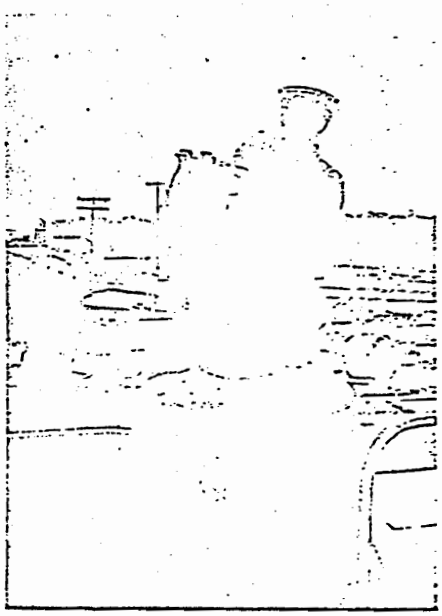


Fig. 10. The worker who opens the dome cover of a tank car or tank truck should wear suitable protective equipment and should stand to one side, upwind of the path of the escaping gas.

24. Tank trucks should be parked on ground which is level or slopes slightly downward toward the rear (Fig. 9). Tank cars should be on a level track with brakes set and wheels blocked. They should be protected by derails or locked switches and by standard warning signs.[16,17,18,30,31,32]

25. Frequently, the tank car or tank truck will be under gas pressure and will contain a high concentration of hydrogen sulfide. The worker should wear suitable protective equipment and stand to one side, upwind of the path of the escaping gas (Fig. 10). The dome cover bolts should be slowly loosened (with non-sparking tools) to vent the gas pressure, or if so equipped, a vent valve may be used. Then the dome cover should be opened and the condition and level of the contents inspected. If steaming is required, this operation and subsequent unloading procedures should follow detailed instructions of the supplier. Care should be taken against possible dangerous concentrations of hydrogen sulfide in the vicinity of the tank during steaming and during the venting of the tank after unloading if air pressure was used. To prevent the accumulation of hydrogen sulfide under pressure, storage tanks, ships, and barges have large vents which are never closed and which are steam jacketed to prevent their

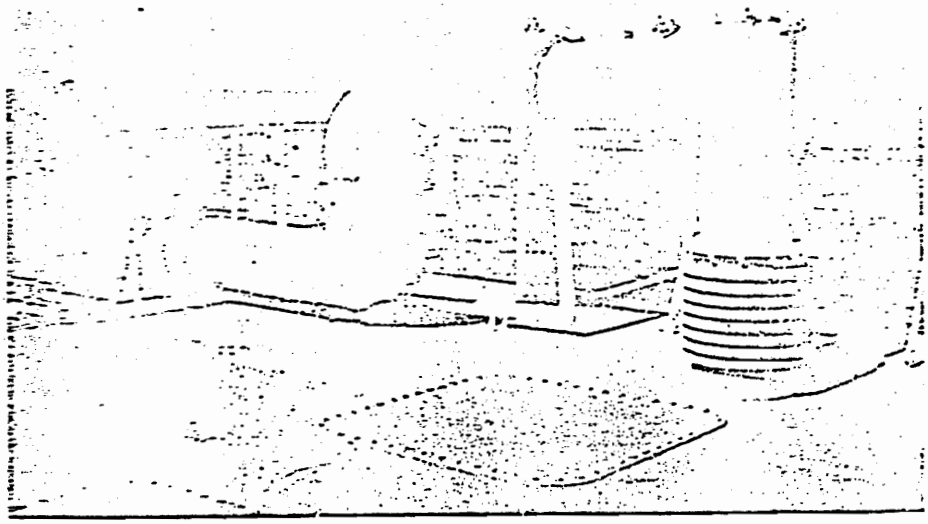


Fig. 11. Insulated, steam-heated vents on cargo tanks remain open at all times and prevent accumulation of hydrogen sulfide in ships.

plugging with sublimed sulfur (Fig. 11).[16,17,18,22]

26. No sparks, smoking, open flames, or welding should be permitted near any opening in a liquid sulfur pit, storage tank, tank car, or other holder. The explosion hazard is greatest in the vapor space of a pit or tank which is being filled, or of an unvented tank truck or tank car. Before filling, tank cars or trucks should first be grounded.[9,20]

27. Manholes and other large openings should be protected with guard rails or gratings. Pit covers or tank covers which may corrode should not be used as walkways. Independently supported walkways should be provided.

28. To maintain liquid sulfur in the preferred temperature range for handling, that is 270 to 290 F, specially designed steam-jacketed or steam-traced piping, valves, fittings, and pumping equipment are used. Sulfur and steam piping should be insulated to eliminate the hazard of burns. There are no unusual hazards associated with liquid sulfur piping.[14,19,22,24,25] However, pipes should be guarded against corrosion caused by contact with water and steam. They should be inspected periodically.

29. A hot sulfur tank should not be entered. The tank should be emptied as far as possible, cooled, and thoroughly purged with clean air until tests with a hydrogen sulfide detector show that the air in the bottom of the tank is safe to enter. Neither welding nor cutting with a torch should be done unless the air space in the tank is shown to be free of combustible gas, or unless the air is displaced with inert gas.[20,37] If inerting must be resorted to, the worker must be supplied with air or oxygen as described in paragraph 31.

Personal protective equipment

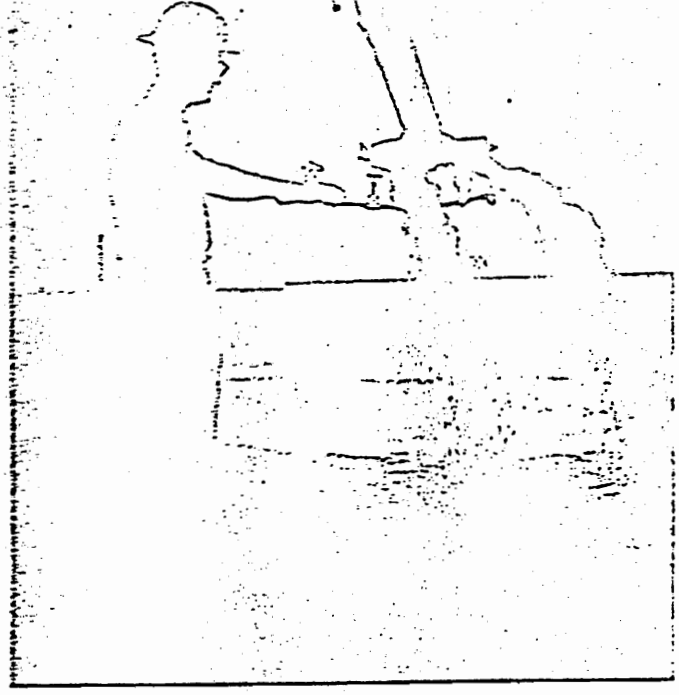
30. Any person handling liquid sulfur should wear a hat; safety glasses with side shields, and a face shield. (In some cases, a full hood is used.) He also needs a long-sleeved shirt; fabric or heat-resistant gloves—without gauntlets, but long enough to overlap the shirt cuffs; laced high-top safety shoes or boots; and trousers long enough to cover the shoe tops (Fig. 12). Galoshes with buckle or zipper closures are also adequate. In no case should open-top boots, low-cut shoes, sandals, sneakers, or perforated shoes be worn.[16,17,18,22,30,31,32]

31. In the routine handling of liquid sulfur in adequately ventilated premises, respiratory protective equipment is not required, but it should be available nearby. If a man must enter an area in which the air is contaminated with hydrogen sulfide, or with sulfur dioxide as in the case of a fire, he should be equipped with air line respirator, hose mask with blower, or self-contained breathing apparatus. The face-piece must protect the eyes. He should be provided with safety belt and life line; and another man should stand by to haul him out if necessary (Fig. 13). Anyone who might have to use respiratory protective equipment should be thoroughly trained and regularly checked for proficiency.[29,36,38]

Fire hazards and extinguishment

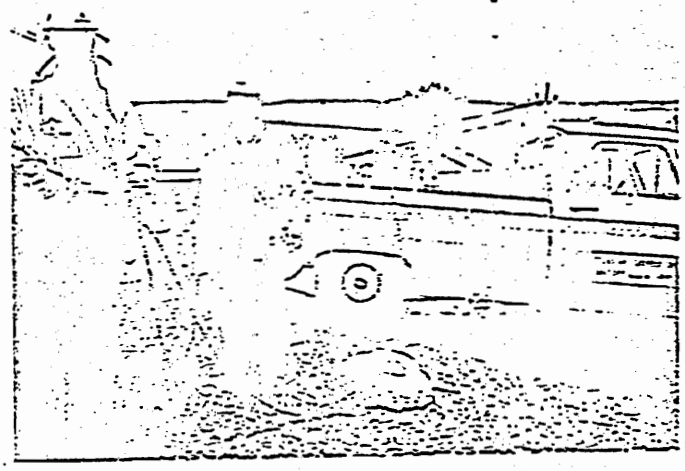
32. If a tank of liquid sulfur does liberate hydrogen sulfide as described in paragraph 12, the gas can form an explosive mixture with air. At about 80 F, the explosive range is between 4.3 and 46 per cent of hydrogen sulfide by volume.[27] At liquid sulfur storage temperature, about 270 F, the lower explosive limit is roughly 3.3 per cent.[29] Mixtures of hydrogen sulfide and air at temperatures below 500 F do not explode spontaneously, but require a source of ignition such as a spark or flame.[27] Sulfur itself has a flash point between about 335 F and 370 F, depending on purity.[9] It burns but does not explode. Some kinds of iron sulfide corrosion products smoulder on exposure to air; they give off sulfur dioxide gas and sometimes generate enough heat to ignite liquid sulfur.[15,22] (Several storage tank and tank car fires appear to have been caused this way, and in nearly all cases excessive steam temperature was apparently a factor.)

33. The best way to prevent a hydrogen sulfide gas explosion is to provide good ventilation, either



sleeved shirts, heat-res... gloves without gauntlets, and laced, high-top safety shoes, as well as head and eye protection.

Fig. 13. The workman preparing to enter an empty liquid sulfur tank wears a full-face mask attached to a clean air line. He has a lifeline attended by an outside man with suitable rescue equipment.



by natural or forced draft.[9]

34. A sulfur fire in a closed container can be smothered by closing all vents. If the tank is large, the sulfur gets very hot before the fire goes out, and must be allowed to cool before vents can be opened again. It is preferable to smother the fire with steam or to use water fog. (A solid stream of water hitting hot sulfur in a closed tank may cause a steam explosion.) Inert gas is less effective, and rarely available in sufficient quantity. Before air is again admitted, the fire must be completely extinguished, and the sulfur must have cooled back to normal temperature.[9,16,17,18,22]

35. A sulfur fire in the open should preferably be extinguished with water. (Again, water fog is more advisable than solid streams.) If, for any reason, water cannot be used, the burning sulfur can be covered with dirt, sand, or other inert material.[9,16,17,18,22]

Electrical equipment

36. It has been the experience of the sulfur industry that electrical equipment meeting the requirements for installation in Class II, Group G locations, according to the *National Electrical Code*, is satisfactory.[9]

Symptoms of poisoning

37. Sulfur is a mild irritant. It has no immediate adverse effect other than irritation of the eyes, and no long-term effect.[19,20,21]

38. Toxic reactions resulting from exposure to hydrogen sulfide gas are usually acute. Inhalation of a high concentration will produce a dramatically swift poisoning with complete arrest of respiration. The individual falls, apparently unconscious, and may die without moving again.[28]

39. In less acute poisoning, the signs may be nausea, stomach distress, belching, cough, headache, irritation of the eyes, nose, and throat, and blistering of the lips. Also, skin contact with hydrogen sulfide may result in irritation.[28]

40. Exposure to sulfur dioxide gas results in immediate and severe irritation to eyes, nose, and throat. Neither systemic effects nor chronic effects are known.[22,23]

First aid

41. A worker who has been overcome with hydrogen sulfide or sulfur dioxide must be carried at once to fresh air. Artificial respiration must be started immediately if breathing has stopped. If available, oxygen should be administered by a trained operator. With proper equipment and training, breathing can be restored even in a contaminated atmosphere.[25,26,29,30,28]

42. Inhaled hydrogen sulfide often acts so quickly on the lungs that there is not time to call a doctor before an attempt must be made to revive the victim. The following steps, therefore, should be taken in the order given:

a. Protect yourself.
b. Summon aid, then proceed with the rescue.
c. Move the victim at once into fresh, pure air.
d. Send for a doctor and an ambulance.
e. If the victim is unconscious and not breathing, immediately apply an approved method of artificial respiration and continue it until natural breathing is restored or until the victim is pronounced dead by a physician.
f. Keep the patient warm.
g. If it is available, give oxygen mixed with 5 per cent carbon dioxide through a resuscitator.[25] In the initial treatment of the victim, if oxygen mixed with 5 per cent carbon dioxide is not available, it is better to give straight oxygen than none at all.

Treatment of burns

43. On being burned by contact with liquid sulfur, clothing and exposed skin is covered with a thin, hard coating of solidified sulfur. Liquid sulfur burns over a small area should be covered with a clean, dry dressing. The victim should be treated for shock, and removed to

Do not remove the sulfur. When greater areas are burned, no attempt should be made to remove clothing or sulfur from the affected parts because of the danger of tearing the flesh. Instead, cover the affected area with a clean cotton sheet or similar material. Normally, application of burn ointments complicates the removal of foreign matter from the burned area when treatment begins in the hospital.[22]

Medical examinations

44. A pre-employment physical examination should be made of all applicants for work involving possible exposure to hydrogen sulfide. Workers having eye and nervous diseases or any severe illness should not be employed in operations with potential exposure.[27]

45. Subsequent physical examinations of personnel who work on operations involving hydrogen sulfide can be made at intervals determined by the physician in charge.[27]

Waste disposal

46. Small amounts of sulfur can best be disposed of by burning, if this can be done without hazard to personnel or without violating air-pollution regulations. Sulfur exposed to the weather or buried at moderate depths will slowly generate sulfuric acid. If the resulting acidity is objectionable, the sulfur can be mixed with four times its weight of crushed limestone, marble, or shell, and then buried.

ACKNOWLEDGMENT

This data sheet was prepared for the Engineering and Research Committee of the Fertilizer Section, National Safety Council. It has been extensively reviewed by members of the National Safety Council, representatives of Chapters of the American Society of Safety Engineers, and other qualified reviewers. It has been approved for publication by the Technical Publications Committee of the Industrial Conference of the Council. Photos were furnished by The Sulphur Institute, Texas Gulf Sulphur Company, and Freeport Sulphur Company.

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This data sheet, one of a series published by the National Safety Council, reflects experience from many sources. Not every acceptable safety procedure in this field is necessarily included. This data sheet should not be confused with USA Standards, federal laws, insurance requirements, state laws, rules, regulations, or municipal ordinances.

DEPARTMENT OF STATE
AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D.C. 20523

January 20, 1976

MEMORANDUM

TO: TA/OST, Mr. Henry Arnold

FROM: SER/ENGR, M. M. Vogel

SUBJECT: Your Sulphur Bonding Project

Attached is a memorandum from Bob Snell which, while not based upon any great volume of research, directs some questions at the environmental aspects of your sulphur bonding project which I believe are worth attention. You are aware that we have assisted in this project since its inception, and have evaluated some operations in Colombia.

I recommend that you give serious thought to Mr. Snell's findings and to the possible need to alter the project to eliminate or at least ameliorate what appear to be significant detrimental environmental consequences.

We are, as usual, at your service.

Attachment:
Memo from Snell to Vogel
Dated 1/19/76

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OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : SER/ENGR, Mr. M. M. Vogel

DATE: January 19, 1976

FROM : ENGR/SP, Robert C. Snell

SUBJECT: Comments on Sulphur Bonding Project

The Sulphur Bonding Project financed by TA/OST under a contract with the Southwest Research Institute is investigating the use of sulphur as a substitute for cement or lime mortar in unit masonry construction.

The procedure used on the first houses built involves the melting of sulphur in an open metal container, over an open fire. The molten sulphur, at a temperature of approximately 100° C, was then ladled out and applied to masonry units which were then set in place in the wall being constructed. After the wall, or building walls, were completed to the desired height a generous coating of molten sulphur was applied to exterior and interior surfaces with mops, brushes or trowels.

Four houses have been constructed in Colombia, S.A., in residential housing projects. These houses represent a field demonstration of techniques, materials and methods of construction using the sulphur as the bonding material for unit masonry produced locally.

Some reflection on the methods and materials involved and the intended occupancy of the houses as dwellings has produced a concern as to the environmental consequences of use of this material. A review of the characteristics and behavior of sulphur in this application and some of the environmental consequences developed the following data, implications and conclusions.

Sulphur, exposed to oxygen, oxidizes into the compounds sulphur dioxide (SO_2) and sulphur trioxide (SO_3). Where temperature and humidity are low, this process is quite slow producing the resulting compounds in a gaseous state. This oxidation process is rapidly accelerated with increases in temperature. The following table gives probable SO_2-SO_3 equilibrium concentrations in an enclosed space at various temperatures.

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TEMPERATURE °F	TEMPERATURE °C	EQUILIBRIUM Parts per Million SO_2 & SO_3	REMARKS
104	40	.02	a common ambient temperature
for comparison		.2	8 hour safe exposure, OSHA Regulation
203	95.5	5.	Melting point of Sulphur
212	100.	7.	
220	104.5	10.	15 min. safe exposure, OSHA Regulation
284	140	147.	
500	260	23,000.	Flash point
883	445	1,000,000.	Boiling point

In environments where high humidity or other conditions make water (H_2O) readily available these gases combine with the water to form sulphurus acid (H_2SO_3) and sulphuric acid (H_2SO_4). Ignoring the corrosion which would be produced by these acids in the room, a potentially much more dangerous condition would exist, in rooms with little or no water vapor. The inhabitants would then inhale these gases causing the acids to form in the lungs. Even if each exposure was of relatively short duration, the resulting lung damage could be cumulative with repetition of exposure. This danger is especially difficult to detect since these gases are odorless, tasteless and colorless in dilute quantities, still above the danger point.

The oxidation (burning) of wood in the house would produce equally dangerous CO and CO_2, but it is accompanied by visible evidence of the oxidation process. This visible evidence causes the occupants to flee. Oxidation of sulphur is not accompanied by such visible and alarming evidence and the danger and is therefor much more insidious. In case of a fire in the house, the rapid production of SO_2 and SO_3 due to rapidly rising temperatures could make the room or any part of the house a death trap in a very short time. The greatest danger under such conditions would be to infants, invalids or sleeping occupants in adjacent rooms.

28

The toxicity of sulphur chloride is rated equal to phosgene or chlorine gas while the toxicity of SO_2 and SO_3 is rated equal to hydrogen cyanide and 10 times as toxic as carbon monoxide and chloroform.

This review has not addressed the environmental aspects of the process and material with respect to the external environs of such housing units. Such a review cannot be made on the basis of site data available. A careful review of this aspect of the consequences of this project may be justified.

Conclusions:

1. A careful and searching examination of the suitability of this project should precede any further field demonstrations of the process.

2. A decision should be made as to a method of eliminating the hazards in buildings already constructed in foreign countries.