

CHAPTER 2

USE OF SULPHUR IN PAVEMENT CONSTRUCTION

2.1 General

As described earlier, the uncertainty of supply of bitumen which reflects in a substantial increase in the price of the material as shown in Figure 1. has prompted the search for an alternative to asphalt cement. Sulphur is the alternative that appears to have the greatest promise.

In this chapter the elemental sulphur and its use as a component of mixture in paving materials will be discussed. Specifically, Sulphur Extended Asphalt (SEA), Sand-Asphalt-Sulphur (SAS) and Sulphlex binders are the three materials to be described.

2.2 Fundamental Properties of Sulphur

Sulphur is one of the basic elements. It has an atomic number of 16 and atomic weight of 32.06. The specific gravity of solid sulphur is approximately 2.00 at 16°C and decreases to 1.78 as temperature is raised to 149°C. At standard conditions of temperature and pressure it exists as a friable yellow solid, its colour becomes progressively lighter as the temperature is lowered. At its melting point, about 226°C, sulphur is a light yellow, transparent and relatively nonviscous liquid. The viscosity of the liquid sulphur is approximately the same at the temperature range between 127-150°C, the viscosity is lowest at a temperature of 150°C. In contrast, the viscosity increases dramatically at temperature greater than about 169°C, Figure 2 shows viscosity-temperature relationship for liquid sulphur.

The tensile strength of bulk elemental sulphur is reported to range between 1,240 to 1,930 KPa. The compressive strength of bulk elemental sulphur is about 12,400 KPa.

The unique properties of sulphur enable it to be utilized as :

- 1) a binder in combination with other binding materials, as in sulphur extended asphalt.
- 2) a structuring material, i.e. playing the role of the aggregate.

- 3) a separate, independent binder developed by modifying elemental sulphur with various type of plasticizers, Sulphlex is such an example.

2.3 Sulphur Extended Asphalt (SEA)

The use of sulphur as a partial binder substitute for asphalt cement in bituminous concrete pavement was described by Bencowitz and Boe⁽¹⁾ in 1938. They reported that stable mixture of 25 weight per cent sulphur in asphalt could be prepared by mixing the two at temperature of 140°C for two hours with a stirrer at the speed of 325 revolution per minute. Their work indicates that sulphur could be used to replace part of the bituminous binder. Since the middle of 1970s, Canada and France and the U.S. have actively studied and performed field trials of SEA pavements. Garrigues⁽¹²⁾ in France and Kennepohl⁽¹³⁾ and Pronk⁽¹⁴⁾ in Canada developed methods for preparing premixed SEA binders for mixing with aggregates. Mcbee⁽¹⁵⁾ of the U.S. developed a simple, direct-mixing method for preparing uniform SEA paving materials that utilized the high shear mixing action of the pugmill to blend the hot sulphur, asphalt cement and aggregate in asphalt paving plants. Mcbee, Sullivan and Izatt⁽¹⁶⁾ later published a guideline manual for design, quality control and construction of SEA pavements.

The first SEA Test pavement on U.S. public roads was placed in Texas⁽⁴⁾ in 1975 using a preblended SEA binder. The test section of the road, US 69, was 1112.5 meters in length. The binders used were either pure asphalt cement which was used in control sections or a 30-70 weight per cent blend of sulphur and asphalt cement respectively. A post construction evaluation of the test sections, carried out four years after construction⁽¹⁷⁾ indicated that the trial sections are in excellent condition, no incipient distress patterns were detected, rutting was found to be less pronounced in the sulphur-asphalt test sections than in the conventional pavement. A more recent field trials were conducted by the State of Maine in 1980⁽⁵⁾ and Idaho County⁽⁶⁾ in 1982. In the Maine field trials a 30/70 weight blend of sulphur and asphalt was used as the binding agent and the SEA mix was designed by the Hveem method. It was reported that nearly 20 per cent of the required

asphalt cement was saved as a result of using the SEA binder concept. Similarly for the Idaho project, the Hveem method was used to design mixes using a 30/70 weight per cent blend of sulphur and AC-11 asphalt cement.

Interest in the sulphur-asphalt technology in Europe and Middle East was started by Societe National Elf Aquitaine (SNEA(P)) which developed the technology.⁽¹⁸⁾ Interest results from several benefits including:

- Sulphur replaces a portion of the asphalt required in road building, with resulting in economic and supply advantages.
- Energy savings are realized because of lower mixing temperatures during preparation of the hot mix.
- Local substandard aggregates can be utilized.
- Sulphur-asphalt shows improved performance.

Road trials carried out in Europe and the middle East since 1973 using the SNEA technology are listed in Table 1.

Table 1. Sulphur Asphalt Construction Sites (Sulphur R & D 1980)

Location	Length of Pavement, Km	Hot-Mix, Used Tons	Sulphur, Used Tons
FRANCE			
Lacq, May 1973 (Base and wearing courses)	1	4,000	60
Magesq, 1974 (Miscellaneous formulations)	4	6,000	80
Pau, December 1975 (Wearing course)	5.5	7,700	130
Chalon, October 1976 (Wearing course)	10	12,500	250
Paris November 1976	2	3,000	50
Mont Revard, October 1977 (Base course)	1	1,700	25
Lorient, November 1977 (Base course (underdesigned layers))	4	10,000	140
Paris, December 1977 (Wearing course)	4	5,000	100
Montauban, July 1978 (Wearing course)	3	5,000	80
Carcassonne, July August 1978	2	5,000	80
St Etienne, October 1978 (Wearing course)	1	1,300	25
Carcassonne, December 1978 (Wearing course)	1.5	2,000	40
Bordeaux, January 1977 (Base course (60% sand))	0.4	700	12
Auch, November 1979 (Base and wearing courses)	3.5	1,200	180
SPAIN			
Madrid, May 1976 (Wearing course)	1.5	2,800	44
FINLAND			
Helsinki, August 1976 (Wearing course and base)	1.5	1,700	36
BELGIUM			
Waterloo, October 1977 (4 lane highway (wearing course))	1	1,500	25
NORWAY			
Oslo & Trondheim, July August 1978 (Wearing course)	0.75	500	12
POLAND			
Cracow, August 1979 (Base and wearing courses)	2.5	3,000	50
MIDDLE EAST			
Irag (Mosul Babylone), May-June 1977	4	5,300	100
Base and wearing courses			
Kuwait, June July 1977 full depth pavement	1	4,000	70
Miscellaneous (December)			
United Arab Emirates, February 1978	1	5,000	100
Full depth pavement			
Dhahran (Saudi Arabia), November 1979	1	2,500	25
Wearing course			

In France, SNEA has demonstrated by road trials, the feasibility and reliability of the technology to the point where it has now been accepted Commercially. In 1982, 27 Km of Route National 21 in the department of Gers in Southern France were paved with SEA⁽¹⁹⁾. This paving project involved rehabilitation of the existing RN 21 by an 18 cm thick overlay of SEA. The average daily traffic on the route is 5500 vehicles of which about 12 % are heavy trucks.

The choice of SEA paving for this project was based on several factors including:

- 1) Gravel was available at a lower cost than crushed stone. Previous trials with SEA in gravel gave a more satisfactory pavement with SEA than with asphalt cement.
- 2) There was a desire to reduce the consumption of petroleum-base asphalt.

A 30/70, sulphur/asphalt binder was produced in a blending unit developed by SNEA. A total 60,000 tons of SEA hot mix were applied on RN 21, with no major problems reported.

In SEA pavements, sulphur serves a dual purpose, that of a binder and that of a structuring material. In the mixing temperature range the solubility of sulphur in the bitumen is generally 20 wt-pct or greater, depending on the bitumen used. The solubility of sulphur in the laid pavement at ambient temperature is lower, and some of the originally dissolved sulphur precipitates as sulphur crystals. These crystals can impart a structuring role to the pavement depending on the size of crystal formed. Minute crystals will act similar to mineral filler while larger crystals serve as aggregate materials.⁽²⁰⁾

With reference to a report of the sulphur institute (1980)⁽²¹⁾, the advantages of sulphur-asphalt (SA) paving materials may be summarised as follows:

- 1) Since SA mixture is a three-component system (sulphur-asphalt-aggregate) it permits more flexibility in design than regular two-component (asphalt-aggregate) paving materials.
- 2) The strength of SA, as determined by the Marshall method can be designed to be considerably higher, if desired, than that of regular asphaltic mixes.

- 3) The use of sulphur increases the high-temperature stiffness of paving materials, without a corresponding increase at low temperatures. Softer grade asphalt can be used to minimise winter cracking with less danger of deformation at summer temperatures.
- 4) SA improves resistance to water stripping. Aggregate which would otherwise be unsuitable can be used, and the use of anti-stripping agents can be reduced or eliminated.
- 5) Resistance to spillage of gasoline, diesel fuel and other solvents is improved.
- 6) Stress-fatigue characteristics are improved.
- 7) The design thickness can be reduced in some cases up to 40 %

2.4 Sulphur-Sand-Asphalt (SAS)

Studies on the use of sulphur as a means of upgrading poorly graded mineral aggregates have been conducted for approximately 15 years by Shell Canada, Ltd. As a result, the first practical material, a sand-asphalt-sulphur^(2, 3) was produced. The process has been patented under the trade name of Thermo-Pave. In this material, molten sulphur is combined with paving grade asphalt cement and suitably graded sand. It is clear that such a material would be viable where mineral aggregates are scarce or expensive because of transportation cost. The properties of SAS were reported to be similar to those of asphaltic concrete. A number of full-scale pilot projects were carried out using Thermo-Pave. One such experimental project was constructed in Texas⁽²²⁾ under the sponsorship of the Texas Department of Highways and Public Transportation, the Federal Highway Administration, the U.S. Bureau of Mines and the Sulphur Institute. The basic objective of this experimental project was to determine whether it was feasible to design a sand-asphalt-sulphur pavement material using natural sand sulphur and asphalt in lieu of quality aggregate and asphalt cement and then to construct a durable pavement surface using conventional batching plant with minor modification for adding the liquid sulphur into the pugmill, and transporting and placing the sand-asphalt-sulphur mixture. Although minor problems were encountered, as would be expected when dealing with a new type of material, the result of this experimental project conclusively showed that a properly designed sand-asphalt-sulphur paving material can be successfully placed using the techniques developed by

Shell Canada. For this particular project, 17 kg of sulphur and 105 kg of sand replace 135 kg of quality aggregate. The sulphur acted as a structuring agent that hardened within the voids of the bitument-coated aggregate to provide a strong pavement with remarkable elastic properties.

2.5 Sulphlex or Plasticized Sulphur Binders

In this relatively new binder, sulphur is modified by plasticizers to give a material called Sulphlex, no bitumen is involved. It is, thus an independent pavement binder apart from bitumen and portland cement. The Southwest Research Institute⁽²³⁾ (SWRI) has, during 1978-1980, developed a series of these so called Sulphlex binders which are basically a family of binder materials that have been formulated to give engineering properties ranging from bitumen to portland cement. They are composed of 60-80 per cent by weight of elemental sulphur and 40-20 per cent of a mixture of plasticizers. The plasticizing agents currently are mostly derived from petroleum, but it is possible to derive these agents from coal or agriculture materials.

The SWRI has examined over 250 different binder formulations involving, dozens of potential plasticizing agents. The compositions of three of the more promising Sulphlex binders are shown in Table 2.

Table 2. Compositions of Sulphlex Binders

	Sulphlex Binder		
	#126	#230	#233
Sulphur	61%	70%	70%
Cyclodiene Concentrate	13%	15%	12%
Dipentene	-	15%	10%
Vinyl Toluene	13%	-	8%
Coal Tar	13%	-	-

The reaction that forms Sulphlex binders is initiated at 150°C. Molten elemental sulphur and the plasticizers are blended and heated to that temperature. The reaction takes place at ambient pressure and is complete in approximately one hour. Once initiated, the reaction is exothermic. The addition of a small quantity of the end product catalyzes the reaction and significantly reduces the reaction time. The properties of the Sulphlex binders are determined by initial choice

of the plasticizers used, how many are used (at least two) and the relative amounts in which they are used. Proper choice allows formulation of flexible binders similar to asphalt cement, or rigid binders which are capable of developing compressive and flexural strength in mixtures similar to portland cement binders, or binders with properties intermediate between these two extremes. Table 3 shows typical properties of a flexible Sulphlex binder, Sulphex-233 compared to AC-20 asphalt cement, while the properties of Sulphlex hot mix are compared with those of asphalt hot mix in Table 4. It is interesting to note that the sulphlex hot mix

Table 3. Properties of Sulphlex vs. Asphalt Binders.

	Sulphlex-233	Ac-20
Penetration (ASTM D 5)	50	55
Ductility (cm, ASTM D 113)	100	100
Softening Point ($^{\circ}\text{C}$, ASTM D 36)	51	55
Viscosity (Centistokes, at 135°C)	139	330
Specific Gravity (at 25°C , ASTM D 71)	1.54	1.02
Thin Film oven test weight loss (Pen. Ration), ASTM D 1754	6%(.5)	0%(.6)
Flash Point ($^{\circ}\text{C}$, ASTM D 92)	180	260

Table 4. Properties of Sulphlex vs. Asphalt Hot-Mixes.

	Sulphlex-233	AC-20
Marshall Stability (Flow) (60°C , ASTM C 1559)	5900(20)	2000(14)
Compressive Strength (ASTM C 39)	2400 psi	1300 psi
Tensile Strength (ASTM C 496)	500 psi	230 psi
Wet-Dry Strength Ratio (ASTM D 1075)	80	95
Freeze-Thaw Cycles (One cycle = 18 hrs at -20°F , 8 hrs at 140°F)	100	100

develops a significantly higher value of Marshall stability than of asphalt hot mix for the 6 per cent by weight of binder content. Love⁽²⁴⁾ considered plasticized sulphur binders to be most revolutionary concept in the highway pavement field since the development of asphalt cement as a binder for flexible pavements. Despite its promising utilization as a future pavement binder, work on Sulphlex is still in laboratory testing phase of development and it appears that more research,

particularly in the area of organic polymer chemistry is needed before the complexity of modification of elemental sulphur with plasticizers can be completely understood.

2.6 Preparation of Sulphur Extended Asphalt Binder

There are currently three main methods for preparing SEA binder:

- 1) Direct mixing of binder components: In this method, the hot components of sulphur, in molten form and asphalt cement are fed directly into the pugmill or the dryer drum, the pugmill provides the necessary mixing action to disperse the sulphur in the asphalt. Figure 3 shows schematic diagram of the method.
- 2) Pre-mixing of binder components. The hot sulphur and asphalt are preblended in an in-line blender and transferred immediately, or following a short period in transitory stage, into a pugmill or dryer drum mixer for mixing with the hot mineral aggregates. The premixed hot binder should be stored only for short periods (minutes) to avoid sedimentation of the heavier sulphur as well as emission of hazardous gases. Figure 4 shows general set up of the system.
- 3) Direct addition of solid sulphur into drum mixer. This method of preparing SEA binder was developed as a result of problems associated with the handling of molten sulphur such as cost of hauling liquid sulphur over a long distance and cooling and solidifying of liquid sulphur. In contrast, solid sulphur in the form of pellets, prills or flakes is more readily available and presents no storage or handling problems. The sulphur handling system is shown schematically in Figure 5.

2.7 Safety precautions

Although sulphur is not considered hazardous material⁽¹⁶⁾, its vapours and gaseous emissions can be toxic, therefore care must be taken when handling sulphur.

Hot sulphur poses the same dangers as hot asphalt or any other hot liquid. Sulphur will burn if ignited. As with handling liquid asphalt, all sources of ignition such as smoking, open flames and sparks must not be permitted near liquid sulphur.

Vapour containing small amount of elemental sulphur may be given off during the preparation and placement of sulphur-bitumen paving mixes.

As the vapour cools, the sulphur crystallizes into small particles which are carried in the air like dust. Sulphur is virtually nontoxic and there is no evidence, that systemic poisoning results from the inhalation of sulphur dust.⁽²⁵⁾ However, the dust can irritate the inner surfaces of the cyclids and may also irritate open cuts of the skin. Goggles and disposable filter masks should be provided to workers in those areas where concentration of sulphur dust is high and objectionable.

In addition to the vapour, emissions of hydrogen sulphides and sulphur dioxide may be present during the preparation and placement of the SEA mix. However, the concentrations of these emissions are usually low or nonexistent when the SEA binder is produced at temperatures below 149°C. Above this temperature gaseous emissions may increase rapidly. It is thus most important to make sure that the mixing temperature is below 149°C.

There are regulations pertaining to sulphur emissions issued by bodies such as the U.S. Department of labor, occupational safety and Health Administration (OSHA). The OSHA regulations apply to three general areas thus:

- 1) In the laboratory, where the sulphur asphalt mixes are designed and tested
- 2) At the hot-mix plant where the raw materials are stored and where the pavement mixes are prepared.
- 3) In the haul truck and at the construction site where the paving mix is placed.

The maximum allowable concentration of hydrogen sulphide, for prolonged exposure, is 10 parts per million (ppm). For sulphur dioxide it is 5 ppm.⁽²⁶⁾ Table 5 lists the toxicity levels for sulphur emissions.

Table 5. Toxicity levels for sulfur emissions

<u>Concentration, ppm</u>	<u>Effect</u>
<u>TOXICITY OF HYDROGEN SULFIDE</u> (27)	
0.02	Odor threshold.
0.10	Eye irritation.
5-10	Suggested maximum allowable concentration for prolonged exposure.
70-150	Slight symptoms after exposure for several hours.
170-300	Maximum concentrations that can be inhaled for 1 hour without serious consequences.
400-600	Dangerous after exposure for $\frac{1}{2}$ to 1 hour.
700	Fatal with $\frac{1}{2}$ hour exposure.
<u>TOXICITY OF SULFUR DIOXIDE</u> (28)	
0.3-1.0	Detected by taste.
More than 1.0	Injurious to plant foliage.
3	Noticeable odor.
5	Immediate irritation to nose and throat.
6-12	Irritation to eyes.
20	Suggested maximum allowable concentration for 30 to 60 minutes' exposure.
400-500	Immediately dangerous to life.

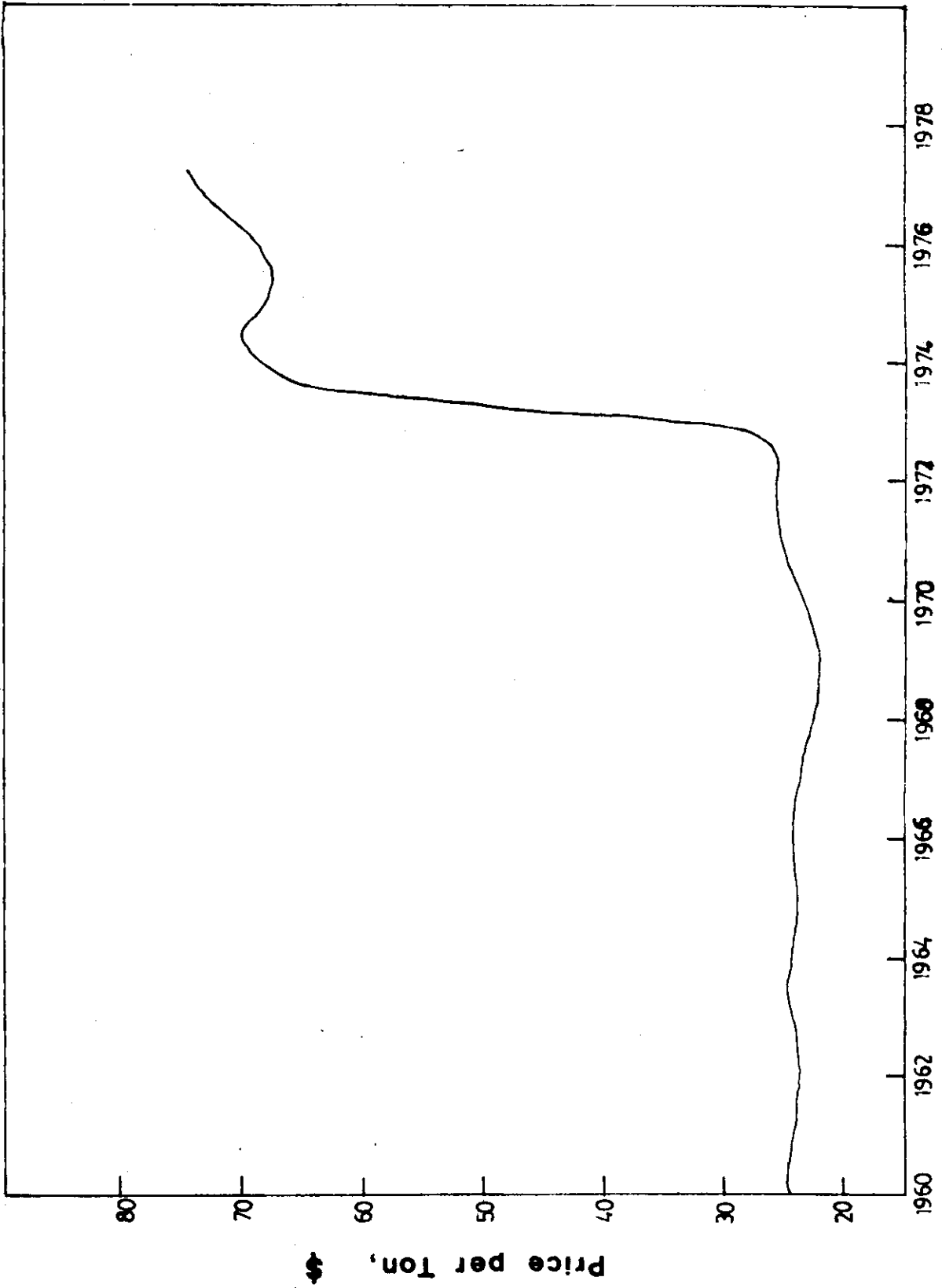


FIGURE 1. UNITED STATES PRICE TREND FOR ASPHALT CEMENT

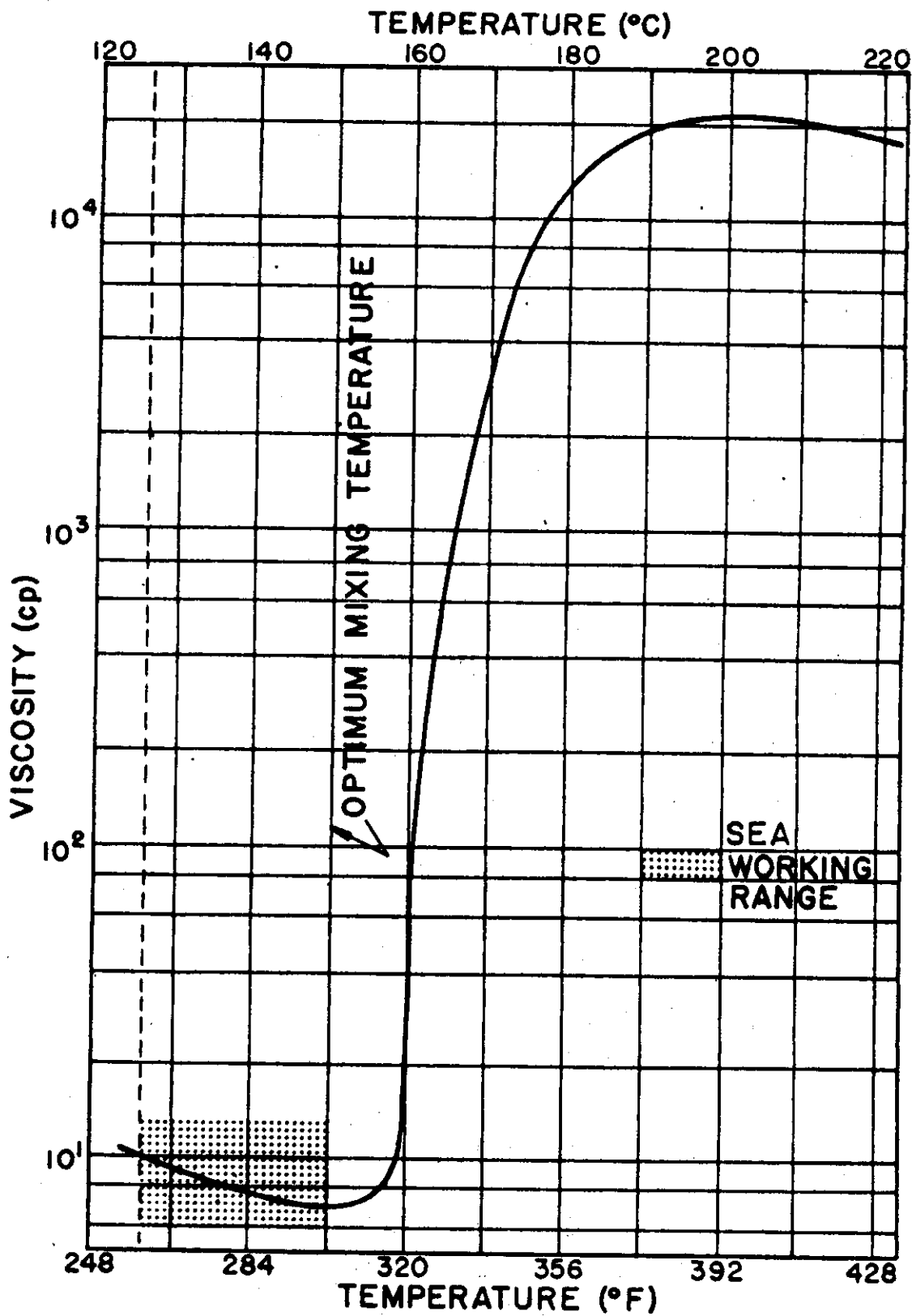


FIGURE 2. VISCOSITY-TEMPERATURE CURVE FOR LIQUID SULPHUR. (after Gross, 1980)

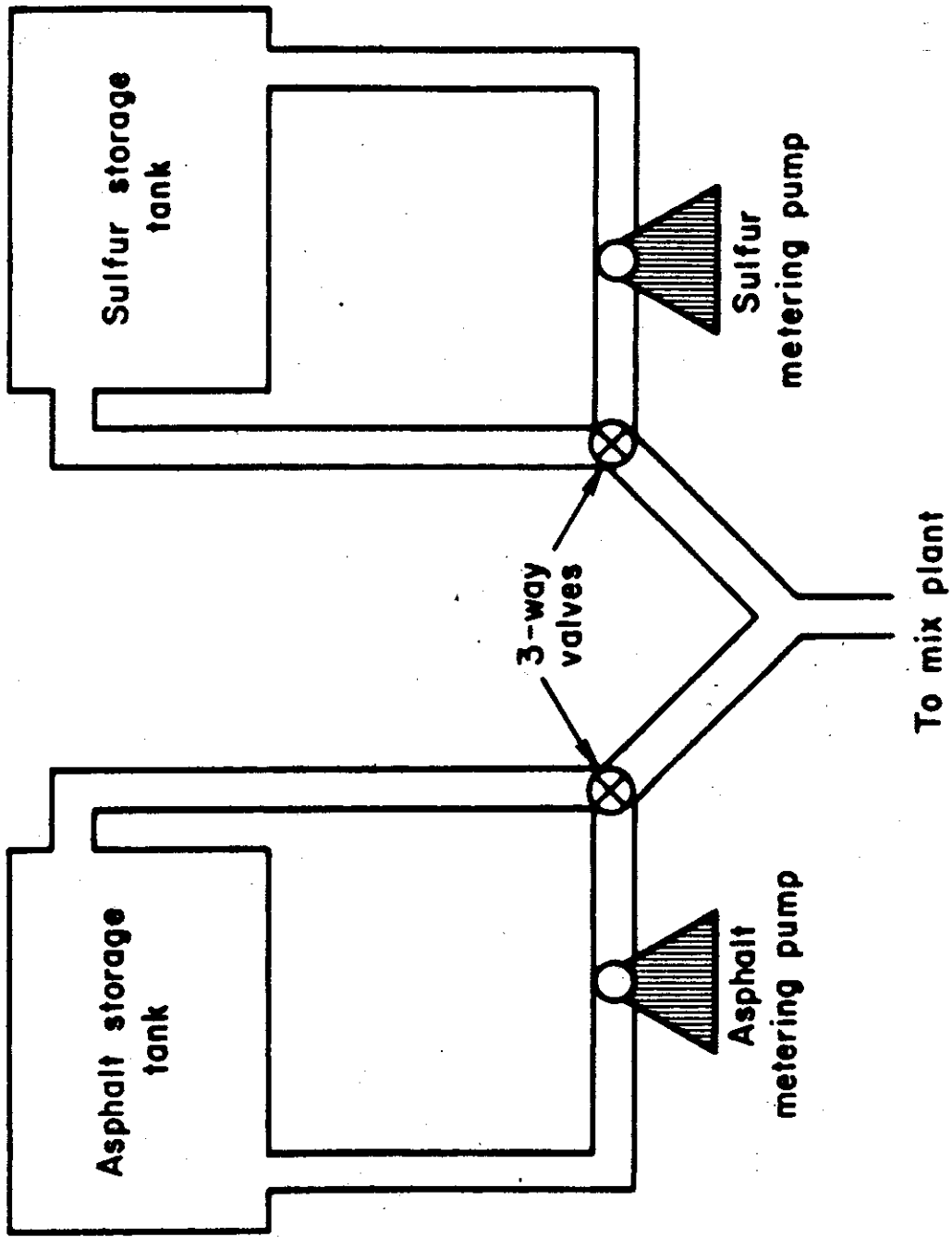


FIGURE 3. DIRECT MIXING METHOD FOR PRODUCTION OF SEA (after Mcbee, 1980)

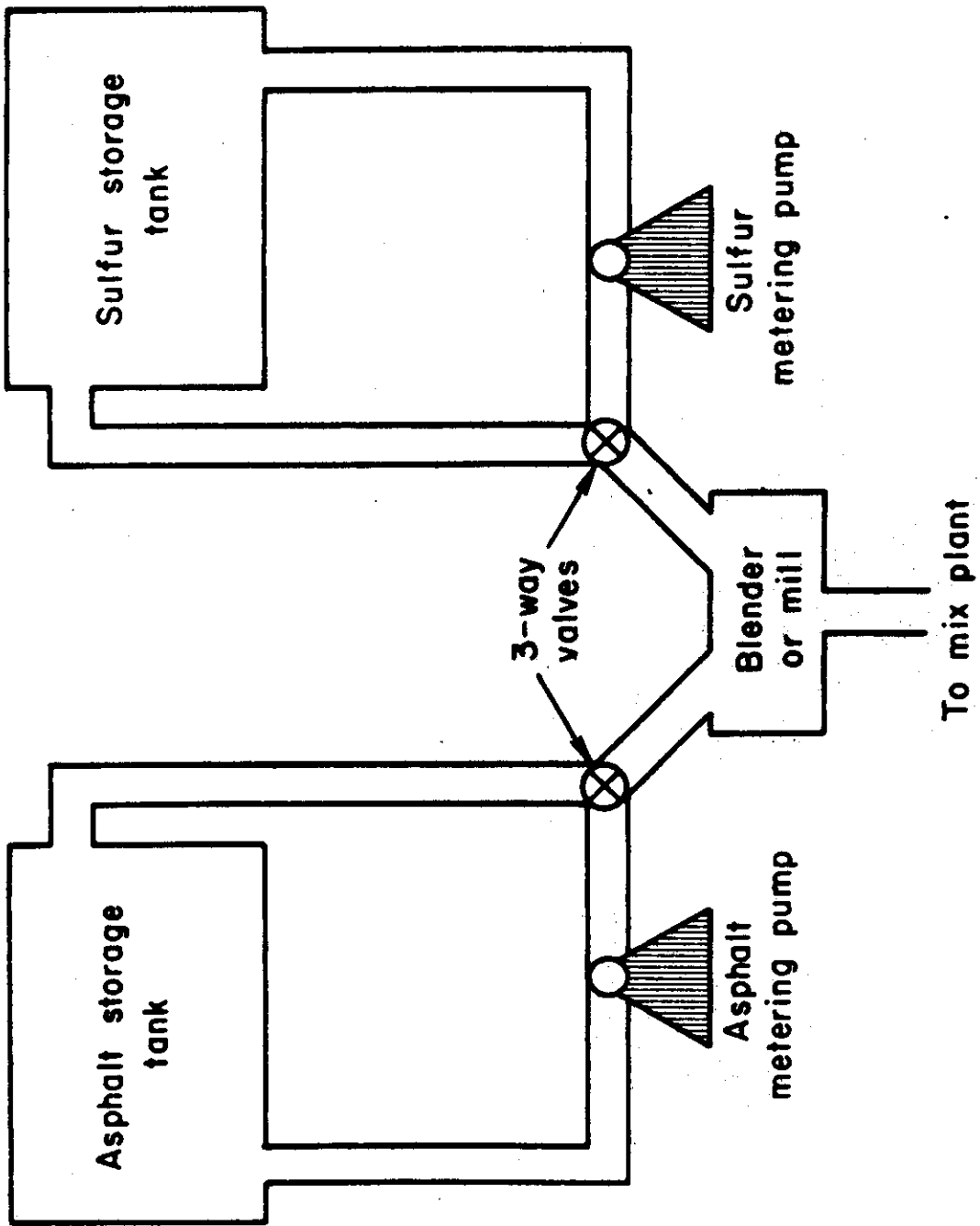


FIGURE 4. PREBLENDING METHOD FOR PRODUCTION OF SEA (after Mcbee, 1980)

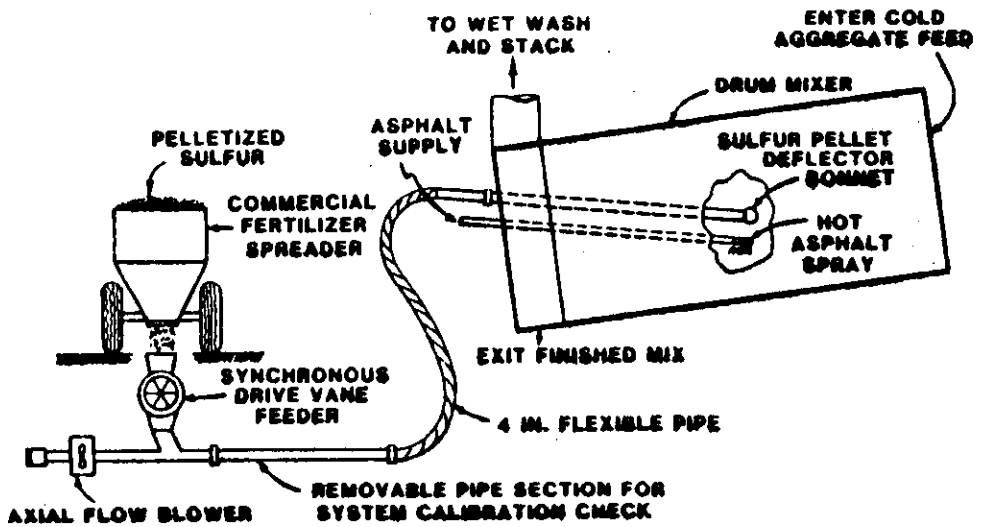


FIGURE 5. SCHEMATIC DIAGRAM OF SULPHUR HANDLING SYSTEM
(after Gallaway 1983)