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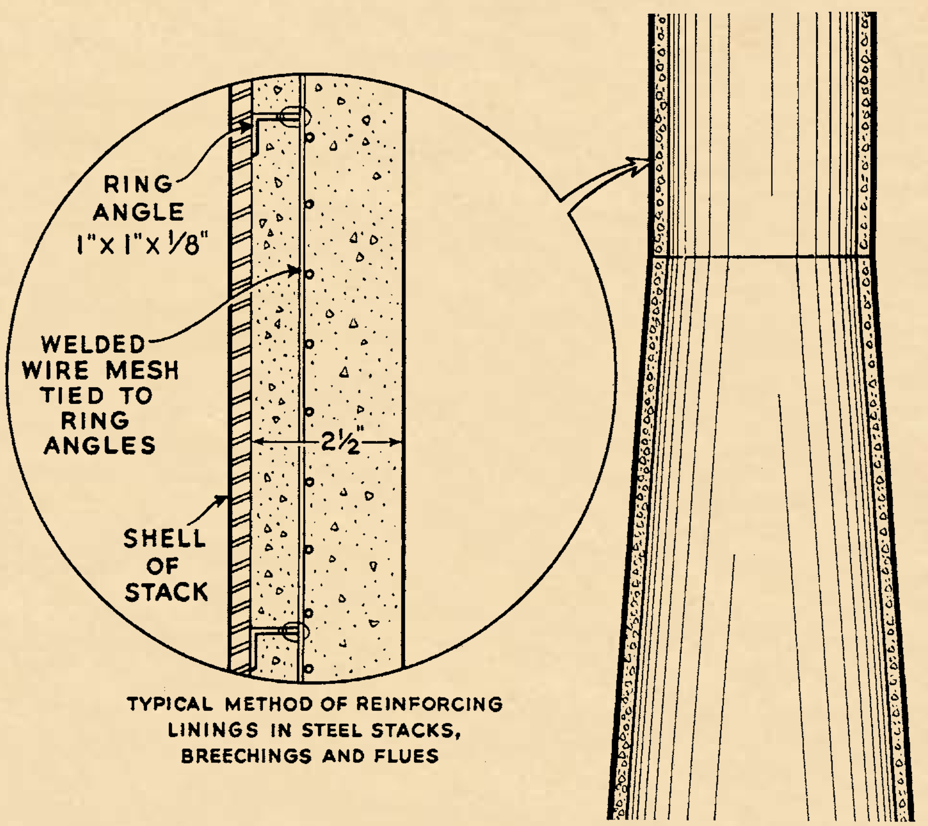
Concrete Linings in Steel Stacks

by G.T. Haddock, Lumnite Division, Universal Atlas Cement Company



Sketch of typical concrete lining in steel stack, showing simple reinforcing system.

WEIGHTS OF CONCRETE LININGS

Aggregate	Maximum Service Temperature	Average Weight of Concrete per Cubic Foot 1:3 Mix	Average Weight per Sq. Ft. 2½ in. Thick (Note 1)	Thermal Conductivity K-factor (Note 2)
Sand	500 F	140 lb	30 lb	——
Trap Rock	1800 F	156 lb	33 lb	10.0
Haydite	2000 F	110 lb	23 lb	3.0
Crushed Firebrick	2200 F	133 lb	28 lb	7.0

Note 1. For estimating purposes add about one pound per square foot for weight of reinforcing steel.
Note 2. Btu/hr/sq ft/inch/deg F.

Shotcrete Classics

From the library of Chris Zynda

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Characteristics of concrete linings . . . Linings are placed in steel stacks to protect the steel from corrosion and heat . . . The high efficiency of modern power plants has intensified the corrosion problem because of low stack temperatures . . . Concrete linings provide necessary protection when calcium-aluminate cement and special aggregates are used . . . Old stacks can be lined and continued in service . . . Simple methods of installing concrete linings insure long life for stacks, as shown by experience under severe conditions.

LINING in a steel stack serves one or more of three principal purposes. (1) The lining protects the steel from corrosion. (2) It provides a refractory for high-temperature conditions. (3) It insulates the stack, raising the temperature of the gas and increasing efficiency. Secondary functions of the lining are to resist abrasion and to provide structural reinforcement.

Operating conditions indicate the characteristics needed in each particular lining. Greatest economy in construction, operation and maintenance results from selecting a type of lining which will meet the service requirements without additional expense for properties which are not needed. For example, it is not economical to install a refractory lining for higher temperatures when gas temperature will never be over 500 F.

Concrete linings allow selection of physical qualities because the properties of the concrete depend on the aggregate and the cement which are used. Also, such linings allow for installation of the exact thickness which is needed, as the thickness is not governed by the use of any standard-size units. If the engineer finds that a 3½-in. lining is needed for insulating effect, a 3½-in. lining can be installed as easily as one of any other thickness.

The type of cement used in making the concrete is determined by the need for resistance to corrosion and resistance to heat. Resistance to either or both of these destructive factors is required in the great majority of power-plant stacks. For that reason, calcium-aluminate cement is commonly specified.

Concrete made with calcium-aluminate cement is highly resistant to the sulphur acids contained in the flue-gas condensate which forms on chimney surfaces. The aggregate also must resist the acid attack. Siliceous sand meets this requirement, but can only be used at temperatures below 500 F. Fired clay aggregates, such as crushed firebrick and Haydite, are resistant to the corrosive action and to heat.

High-Sulphur Fuels Aggravate Corrosion

The need for corrosion-resistant linings wherever sulphur compounds are present is generally recognized. The high operating efficiency of modern power plants results in the reduction of flue-gas temperatures and of the volume of excess air. As a consequence, stack temperatures tend to be below the dew-point, condensation is increased, and the corrosion problem is magnified. The condition is aggravated with high-sulphur fuels because the increased percentage of SO_3 not only increases the acidity of the condensate, but also raises the dew-point of the flue gas. Yeaw and Schnidman have shown that under these circumstances the condensate may be a fairly strong solution of sulphuric acid.[1]

If the flue gas penetrates the lining, condensate will form on the steel shell and will attack the steel. This effect is especially notable where there is an air-space between lining and shell or a space filled with porous insulating material. Pearson has pointed out that temperatures within the permeable lining and close to the shell will fall below the dew-point at certain elevations in the stack. The area affected will depend on the temperature and composition of the flue gas and on load fluctuation during a day's operation of the boilers. Inspection of thirty-three brick-lined stacks showed evidence of corrosion of the steel in all cases, deterioration being most marked in the top half of the stacks.[2]

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1 Jesse S. Yeaw and Louis Schnidman. Dew Point of Flue Gases of Fuels Containing Sulphur. Power Plant Engineering, Jan., Feb., March, 1943.

2 Arthur S. Pearson. Deterioration and Maintenance of Power Plant Structures. Power Plant Engineering, August, 1943.

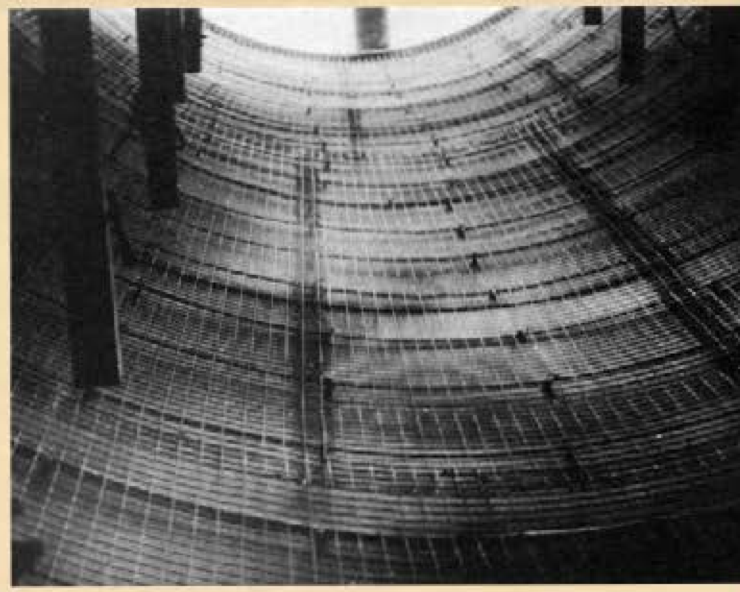

Fig. 1: Reinforcing system for concrete lining in steel stack. Square nuts welded to shell, horizontal rods and wire fabric tied to nuts. Industrial power plant stack, 15-ft diameter, before placing a 2-3/4 in. lining of insulating concrete

The solution of the problem is to install a lining which is resistant to corrosion and which keeps the aggressive condensate away from the steel shell. This can be done with corrosion-resistant concrete placed in intimate contact with the steel. There is then no air-space or porous layer between the lining and the steel. The concrete lining may be cast in place, plastered against the shell, or shot on with a cement gun. In any case, the steel is not exposed and the corrosion-resistant lining provides the surface on which condensation occurs. Close contact between lining and steel is maintained during temperature changes, so there is no "breathing" to draw the acid through the lining and onto the steel.

Special Investigations

Present remarks on corrosion resistance apply to power-plant stacks or to those which discharge gases from sulphur-bearing fuels. Where corrosive agents other than combustion products of such fuels are involved, the resistance of the lining material must be determined by investigation, preferably by trial under actual operating conditions. In some smelters, chemical and processing plants, the stack gases may contain aggressive agents which will attack either the cement or the aggregate in a concrete lining. For these unusual conditions, it is practically impossible to predict the resistance of any lining material unless a trial section can be placed in the flue or chimney for observation.

The effect of heat on stacks is as important as that of corrosion, but it is more easily predictable. The designer of a stack generally knows the cycle of operating temperatures and he can allow for flash temperatures and secondary combustion. As a rule, it is not necessary to provide for temperatures above 2000 F in power-plant stacks. In fact, that temperature is considerably higher than need be anticipated in ordinary service. Consequently, a high-grade refractory lining is not needed unless called for by special service conditions.

Concrete for service above 500 F is known as heat-resistant concrete. It must retain strength under continued exposure to heat and must not disintegrate as a result of frequent cycles of heating and cooling. Concrete made with calcium-aluminate cement and a refractory aggregate has the necessary heat-resistant properties. This type of cement is used for making refractory concrete suitable for service at temperatures much higher than those found in power-plant stacks. But concrete with a service limit of 2000 F affords the greatest economy because of the availability of low-cost aggregates.

Aggregates commonly used for heat-resistant linings in stacks are Haydite and crushed firebrick. Haydite is an expanded, burned shale which is widely used as light-weight aggregate for structural concrete. Crushed firebrick, graded to suitable sizes, is the aggregate most frequently used with calcium-aluminate cement in making refractory concrete. So far as stack linings are concerned, the principal difference between these two aggregates is in the weight and insulating effect.

Trap-rock screenings can be used for aggregate where weight and insulation are not important. Concrete made with calcium-aluminate cement and trap-rock is good for temperatures up to 1800 F. It offers excellent resistance to corrosion and abrasion. Trap-rock has the advantage of being an inexpensive, natural aggregate, but in many parts of the country it is not obtainable.

Sand should not be used for aggregate when the concrete will be exposed to temperatures above 500 F. The volume-change of the silica particles when suddenly heated above that temperature may cause cracking and spalling. Limestone aggregates, commonly used for structural concrete, are not suitable for stack linings, because they are not resistant to the heat and corrosive action of the flue gases.

Insulation is often an important factor in selecting the type of stack lining. With the concrete lining, a fairly wide range of thermal conductivities is available through selection of the proper aggregate. Haydite concrete, made with calcium-aluminate cement, has a conductivity (K-factor) of approximately 3.0 Btu/hr/sq ft/inch/deg F at a mean temperature of 1000 F. With crushed-firebrick aggregate, the K-factor of the concrete is approximately 7.0. This compares with a K-factor of 8.0 for fireclay brick at the same temperature.

The significance of these conductivities as applied to stack linings is in determining the thickness of lining required to minimize the temperature of the steel shell and to maintain the temperature of the flue gas. The thermal resistance of a 3-in. thickness of Haydite concrete is equal to that of an 8-in. thickness of firebrick. As firebrick linings generally have an air-space or mortar between brick and shell, it can be conservatively estimated that a 2½-in. Haydite-concrete lining is at least equal in insulating value to a lining of 4½-in. firebrick plus air-space.

The relatively thin insulating-concrete lining allows greater effective area of stack for the same diameter of shell. In the example mentioned in the preceding paragraph, the diameter inside the concrete lining would be about 7 in. greater than the inside diameter of the brick lining. For a new stack designed with a concrete lining, the size of the steel shell can be proportionately reduced. In the case of an old, unlined stack in which a lining is placed, the insulating effect will tend to raise the gas temperature, thereby compensating for the reduction in capacity caused by the slight reduction in area.

Weight of the concrete is determined by the aggregate. In lining an old, unlined stack which is supported on structural members, it may be necessary to use light-weight aggregate to reduce the dead load, even though the extra insulation is not needed. Comparison of weights of several types of concrete lining is given in the table on page 2.

Abrasion resistance of a concrete lining does not ordinarily require special consideration in designing power-plant stacks. Pearson states in reference to power-plant flues that the abrasive effect of flue gas is small when not preceded by corrosion.[2] Therefore, a dense, corrosion-resistant lining can be expected to minimize abrasion. The concrete lining has no joints, so another starting-point for abrasive action is eliminated. Where the flue-gas carries an unusually large volume of abrasive particles at high velocity, it is advantageous to use a hard aggregate such as trap rock.

The value of the lining as structural reinforcement is incidental to its primary functions. But the concrete lining is effective in reinforcing the shell against ovaling and in dampening vibration. In repairing a badly corroded, unlined stack, the strengthening and stabilizing effect of a concrete lining is important. The lining may make it possible to salvage a stack which would otherwise have to be replaced.

Installation of Concrete Linings

The lining is essentially a thin slab of concrete in close contact with the steel shell. The structure may be considered as a composite section of steel and reinforced concrete. It follows that the most important construction detail is to obtain an intimate union of concrete and steel. The gunite method has been found to be very effective in achieving this result. But a tight bond with the steel can also be obtained when the concrete is cast in place or plastered on the shell by hand. For a specific installation, the most economical system can be determined by considering size of stack, thickness of lining, availability of equipment and of competent labor.

As the majority of power-plant stack linings are from 2½ to 3½ in. thick, these comments on design and construction refer mainly to gunite and plastered linings. Cast-in-place concrete is more suitable for thicker sections where there is sufficient room to allow the concrete to be worked tightly against the shell.

Before installing reinforcing, the steel shell should

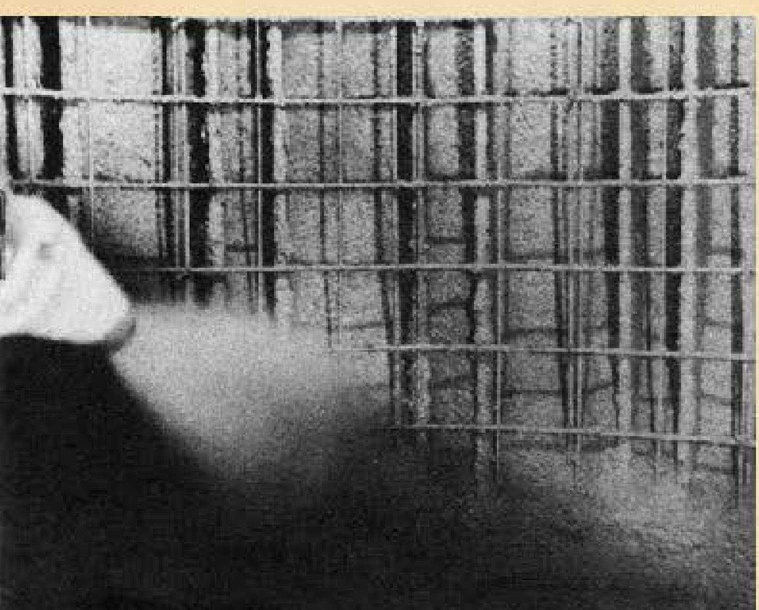

Fig. 2: Shooting concrete lining in steel stack. Section of 200-ft stack, diameter about 8 ft

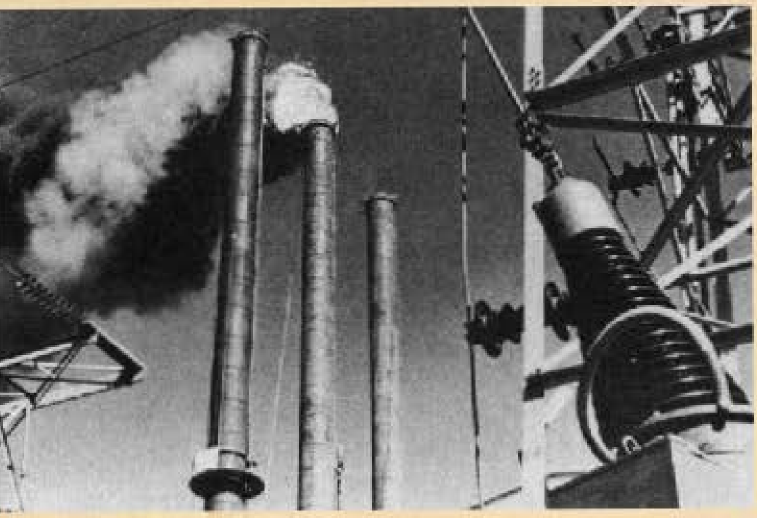

Fig. 3: Three 200-ft stacks at power plant burning acid sludge from oil refineries. Insulating, corrosion-resistant concrete linings protect steel under unusually severe conditions

be cleaned to remove rust, soot and dirt. In old stacks, it is desirable to sand-blast the steel. In new stacks, the inside surface of the steel should not be painted. If a preservative coating has been applied, the coating should be removed in order to insure a tight bond with the concrete.

Reinforcing usually consists of wire fabric attached to hangers which are spot-welded to the inside of the shell. Welded wire fabric with a 3 by 3-in. mesh is preferred. The diameter of the wire should be approximately ⅛ in. or No. 10 gage. (Such as A.S. & W. 33-1010). The fabric may be either plain or galvanized. Any similar system of reinforcing may be used, provided that it is sufficiently open to allow the concrete to fill the space between reinforcing and shell without arching or hanging. A simple method of placing reinforcing is to tie the wire fabric to short lengths of 1 by 1-in. angles which have been spot-welded to the shell. Special hangers have been designed for this purpose, but any arrangement that will hold the fabric in place and allow for easy installation is satisfactory.

Location of reinforcing in the concrete section is most important, especially for a high-temperature lining. With a 2½-in. lining, the fabric should be about one inch from the surface of the steel. Care must be taken to see that the fabric is not placed any closer to the inside face of the lining than is necessary. If it is too close to the hot face of the concrete, the steel may reach a temperature at which it will be oxidized or reduced in strength. For corrosion resistance, the steel should have a cover of at least 1 in. of concrete.

Expansion joints are not usually provided in concrete linings. Experience indicates that the actual expansion of the lining is practically the same as that of the shell. The reinforcing wire and the bond of lining to steel appear to take care of differential expansion. Cracking or breaking away of concrete because of temperature change has not been reported after inspection of any concrete-lined stack.

For a stack lining, the concrete mix generally consists of one part of calcium-aluminate cement and three parts of aggregate, by volume. The sand or refractory aggregate must be well graded to give a workable mixture which will yield dense concrete. Aggregate should not contain particles larger than ⅜ in. For hand-plastered work, it may be necessary to add plastic fire clay to improve the workability of the mix. The fire clay should not exceed 10 lb to the bag of cement. Other plasticizers cannot be used with calcium-aluminate cement, as they affect the setting action and reduce the resistance to corrosion and heat. The lining should be applied in a single thickness, without laminations.

One of the advantages of using calcium-aluminate cement is the speed with which it hardens. The concrete gains high strength within 24 hr of placing. But the quality of the concrete depends on proper curing at the right time. During the curing period, the top of the stack should be covered in order to eliminate draft. The surface of the concrete should be kept moist by sprinkling.

Breechings and flues are lined in the same manner as stacks. The gunite or plastered linings are especially convenient for installation in curved and tapering flues, and for multiple flues leading into a header. As in stacks, linings resistant to heat and corrosion are generally needed in power-plant flues. Corrosion-resistant linings are particularly desirable in flues which pass from the boiler house into the cooler outside air.

For average power-plant service, the most important requirements are that the lining withstand high temperature at the lower part of the stack and be resistant to corrosion in the upper portion. Both requirements can be met by installing from top to bottom a single thickness of concrete which will resist both heat and corrosion.

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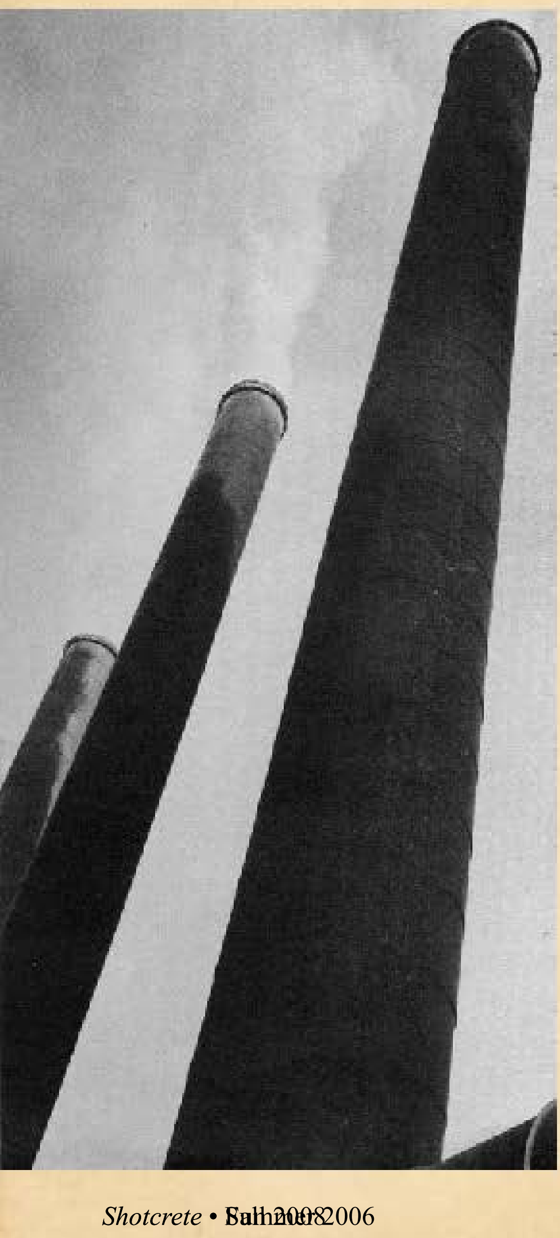
Additional information from Universal Atlas Cement Company

Typical Installations

Construction and service data on several concrete-lined stacks illustrate the characteristics of such linings. All of the linings mentioned were made with Lumnite and installed with a cement gun. Lumnite is a calcium-aluminate cement made by the Universal Atlas Cement Company. It is the only cement of this type made in America. Lumnite is used for corrosion-resistant concrete and mortar, for refractory concrete, and for rapid-hardening structural concrete.



The adhesion of lining to steel was demonstrated in a small stack directly over a pair of industrial boilers in a metallurgical plant. Maximum temperature of flue gas was over 800 F. A 1½-in. gunite lining, consisting of calcium-aluminate cement and Haydite, was installed in breeching and stack. After five years' service, the stack was dismantled because of plant changes. It was found to be exceedingly difficult to remove the lining because of the tight bond between concrete and steel. The concrete lining was very hard and free from cracks.

* * *

The effect of an insulating lining in reducing condensation is illustrated by experience with a stack at a sewage disposal plant in Chicago. The steel shell of the unlined stack, 50 ft high and 6 ft diameter, had been seriously attacked. Condensate with a 3% content of sulphuric acid collected at the bottom. Temperature of gas entering the stack was 400 to 500 F. A 2-in. lining of calcium-aluminate cement and Haydite was installed. The lining kept the gas temperature above the dew-point, so that no condensate formed.

* * *

The value of a corrosion-resistant lining can be judged by experience with several stacks in the water-gas plant of a large eastern utility. Six stacks discharge gases from tar-fired boilers. A gunited lining of calcium-aluminate cement and silica sand was installed in one of the stacks in 1943. After three years' of intermittent service, the lined stack is still in excellent condition and shows no evidence of deterioration. Unlined stacks in this service showed progressive attack during an average total life of about five and one-half years.

* * *

Several stacks on the S. S. Queen Elizabeth were lined during the ship's turn-around in New York on three war-time trips. These stacks are contained within the outside shell which is a conspicuous feature of the ship's outline. A water spray within each stack increased the corrosive action of flue gas from the oil-burning boilers. A gunite lining, 2½ in. thick, was installed on a 24-hour working schedule. The gunite was made with calcium-aluminate cement and crushed-fire-brick aggregate.

* * *

A Pacific coast power company was faced with a serious corrosion problem in several plants where the boilers were fired with acid sludge from oil refineries. The temperature of stack gases was from 300 to 450 F. Under these conditions, the stacks were practically condensers of sulphuric acid. Nine stacks, each about 200 feet high, were lined in 1940. Several others in similar service have been lined since that date and the same type of lining has been placed in ducts leading from boilers to stacks. (Fig. 3)

An unusual type of lining was installed in these stacks. The conditions called for as much insulation as possible plus maximum resistance to corrosion. A 3-in. thickness of gunite, consisting of portland cement and Haydite, was placed next to the shell. This insulating lining was then covered with a 1-in. gunite coat made with calcium-aluminate cement and silica sand. Reinforcement consisted of bars and wire fabric located at about the center of the insulating section. This method involved applying the two coatings in two separate gunite operations, allowing several days for the portland cement to harden before the corrosion-resistant gunite was placed.

* * *

The most common practice in designing concrete linings is illustrated by the sketch on page 2. A single, homogeneous slab of concrete is shot or plastered against the shell. Resistance to corrosion and heat is provided by selecting the aggregate according to the specific requirements of the installations as determined by service conditions.

Fig. 4: Three power-plant stacks, lined with corrosion-resistant concrete. First stack lined in 1941, second in 1943, and third in 1945