Archeologists have used the terms Stone Age, Bronze Age, and Iron Age to delineate successive stages of civilization. During the Bronze Age, humans had learned to use charcoal as a reducing agent, as well as a fuel, to convert mixed ores of copper and tin into molten bronze in clay furnaces. Iron ores were not so easily reduced, and the same process that yielded molten bronze from copper and tin minerals produced, instead, a spongy mass when iron ores were processed. The metalsmith had to learn to beat this mass into a solid, and in the process most of the slag fell away, but some was retained in the iron to produce what is known as wrought iron. Some metalworkers learned how to reheat this mass in the forge so that it dissolved some carbon from the charcoal and was thereby converted to steel. Such secrets were carefully guarded as they provided the balance of power in warfare and in commercial trade.

It was not until the late Middle Ages that relatively large-scale production of iron was achieved with the development of the blast furnace. But the iron produced by the blast furnace (pig iron) contained a high carbon content; it was excellent for casting into shapes in molds, but it wasn’t malleable. Processes were developed to convert pig iron into more malleable wrought iron or steel, and today over 95% of the steel produced still follows the two-step process of blast furnace followed by the converter that burns carbon out of molten iron to produce steel.

However, in developing countries that have fossil fuel reserves, direct reduction processes are being developed that turn back the clock of history and produce “sponge iron.” This product is mixed with scrap steel and the charge is melted in electric furnaces to produce steel. In the United States, “mini-mills” have sprung up to compete with the large integrated steel mills, and their major source of raw material is steel scrap. Almost one-third of U.S. steel production now comes from these electric furnaces, creating a demand for scrap steel. This has raised its price to the point that sponge iron (or DRI, for “direct reduced iron”) will be required for future electric furnace charging with the likelihood that DRI processes will continue to grow.

Nationwide, in both the large integrated mills and the smaller mini-mills, iron and steel making use more water than any other manufacturing industry. A U.S. survey disclosed that the industry water usage was about 5 bgd (13,100 m³/min) of cooling water and 3.5 bgd of process water. Approximately 2 bgd of this water required some form of chemical treatment to make it suitable for use. Of the 3.5 bgd of water that was used in processes, about 65% required some form of treatment before being discharged. As a rough estimate for an integrated mill, 120 tons of water are used for every ton of steel produced (Figure 32.1). A summary of cooling water uses is given in Table 32.1.
The blast furnace is the heart of the iron-making process. Iron ore, coke, and limestone are charged by a skip car to the top of a furnace. Most furnaces range from 16 to 28 ft (4.9 to 8.5 m) in diameter and may be 100 ft (30.5 m) tall. The raw materials, fed in layers to the furnace, are iron ore or pellets, coke, and limestone. In the lower portion of the furnace, hot blast air is injected through a series of circumferential openings called tuyeres, at about 30 to 35 lb/in² (2 bars) and 1800°F (985°C). The air flows upward through the burden of raw materials in the furnace, and gas exits the furnace top at 4 to 5 lb/in² (0.3 bars).

Coke (carbon) reacts with Fe₃O₄ and Fe₂O₃ in the furnace, releasing the iron and producing CO and CO₂ gas. The iron sinks to the furnace hearth where the original impurities in the charge combine with the lime, forming slag, which floats to the top of the iron. The gas leaving the top of the furnace carries fine dust, which is separated and recovered in collection equipment. The combustible exhaust is used in reheating stoves and in generating steam at boiler houses. The iron and slag are periodically tapped and collected in special railcars every 2 to 6 h, depending upon furnace conditions.

To keep this large furnace working efficiently, much of the equipment connected with the furnace uses cooling water at various points. A modern blast fur-

**TABLE 32.1 Cooling Water Use in an Integrated Steel Mill**

| 1. Blast furnace | 8000 | 33 |
| 2. Basic oxygen furnace | 700 | 3 |
| 3. Open hearth furnace | 3600 | 15 |
| 4. Electric arc furnace | 2600 | 11 |
| 5. Continuous casting | 4200 | 18 |
| 6. Bar mills (hot) | 1000 | 4 |
| 7. Plate mills | 4080 | 16 |
| 8. Pipe mills | 24,800 | 103 |
| 9. Cold sheet mills | 3360 | 14 |
| 10. Hot sheet mills | 16,000 | 66 |
| 11. By-product coke plant | 4500 | 19 |
| 12. Sinter strands | 350 | 1.5 |
nace requires 1000 to 15,000 gal/min (63 to 950 L/s) of cooling water. Figure 32.2 illustrates the overall dimensions and general cooling water utilization for a typical blast furnace. This generalized drawing shows that the blast furnace may be constructed in two ways: water sprays may provide cooling water on the outer shell of the furnace, as illustrated on the left side; or, as illustrated on the right side, the furnace may contain stack plates and bosh plates which are hollow passages for cooling water built into the furnace wall. The primary task of the cooling

FIG. 32.2 Blast furnace schematic, showing two types of cooling-water systems.
water on the stack area is to prolong the life of the refractory inside the furnace. The stack area uses about one-third of the cooling water through the furnace.

Where plates are used, these are generally connected vertically in a series of four to seven plates with water flow of 15 to 50 gal/min (1 to 3 L/s) in each series. Temperature rises 12 to 25°F (7 to 14°C) throughout the series. The cooling demand for the refractory decreases as height above the ground increases.

Figure 32.3 shows a hearth and bosh section of the blast furnace. Here, too, either sprays or plates may be used for cooling. The bosh area reaches the maximum furnace temperature, ranging up to 3500°F (1927°C). At this point cooling requirements for the furnace are most critical.

The left-hand side of Figure 32.2 indicates a carbon or closed bosh arrangement. Here, the water sprays are directed at steel plates containing the carbon brick of the bosh area. It may be seen that the spray water is collected in an annular trough directly above the tuyere zone. Also, a stack trough is indicated just at the top of the mantle line. Cooling water from the blast furnace is generally collected in a circular trough surrounding the furnace itself. On the right-hand side of Figure 32.2, a cooling plate arrangement is indicated. Again, plates in this area may be connected in a series of four to six plates with a temperature rise of 12 to 25°F (7 to 14°C).

The cooling water in the lower section or hearth is not shown on the drawing. Normally, large diameter steel pipes run directly through this area to provide cooling. Stack and bosh cooling equipment is easily accessible and changeable at failure. However, should pipes in the hearth area fail, it is impossible to remove and replace them without major overhaul of the furnace. Figure 32.2 also shows the area in which the molten metal and slag reside. Molten materials are generally not allowed to reach a higher level than just below the tuyeres.
In the tuyere area, air preheated in stoves is blown into the furnace. The tuyeres are copper-jacketed nozzles with cooling water in the jackets. Heat exchange rates are high, so it is important that the cooling system be protected from fouling or plugging to maintain adequate heat transfer.

The valves controlling the flow of hot blast air from the stoves to the furnace must also be cooled to prevent failure or jamming.

The basic problem of water chemistry for all of these systems is protection from corrosion, scale, and fouling from silt or microbiological growths. One of these or any combination may exist within a cooling system at any time.

**EXHAUST GAS TREATMENT**

Hot air blown through the furnace is changed in composition and expands in volume. The exit gas velocity is high and entrains solids, principally burden fines—ore, coke, and limestone. This dirty gas passes through a dry dust collector, where a majority of the heavier solids are removed, and then proceeds to a wet scrubbing system. Scrubbing water and the dirty gas collide in a venturi or orifice system where almost all suspended solids are removed—usually over 99%. The scrubbed gas has a Btu value of 85 to 100 Btu per standard cubic foot (1950cal/m³) and is used for heating stoves or firing boiler house furnaces.

The scrubber water containing high concentrations of suspended solids, from 500 to as high as 10,000 mg/L, is normally sent to a thickener or clarifier. Here, the solids are settled, and the effluent water is either sent to the receiving stream, sometimes after additional treatment, or recycled (Figure 32.4).

![Figure 32.4 A clarifier-thickener of this design treats blast furnace gas scrubber water for removal and recovery of solids. (Courtesy of Inland Steel Company.)](image)

The heaviest concentrations of solids settled from the water are normally iron, silica, and limestone. Soluble impurities usually include ammonia, phenols, and cyanide. The chemistry of the scrubbing water continually varies as it is being exposed to hot, dusty gas and then cooled and clarified before recycle. Cooling towers are often used to reduce temperature after the water contacts the hot gas.
Evaporation of pure water vapor in the cooling tower concentrates dissolved solids within the water and affects its chemical balance. This must be taken into account when planning a proper cooling water program, as blowdown is required to control the salinity of the recirculating water, and chemical treatment is needed for control of scale, deposits, and corrosion.

Additional water is used for slag granulation or for slag cooling. Where the water is recycled within a slag pit area, there is usually a high potential for deposition occurring within the recycling lines and pumps, and the water chemistry of these systems must be continually monitored.

There are a number of boiler houses in a steel mill complex, and the boiler house in the blast furnace area is one of the most important. Most of these installations have 900-lb/in² boilers, but some of the older plants continue to operate a few 450- to 600-lb/in² boilers with the higher pressure units. A major use for steam is to operate turbines, which drive the large turbocompressors delivering air to the blast furnaces. A typical turbocompressor discharges 100,000 scfm ft³/min (2830 m³/min) air at a pressure of 30 to 35 lb/in² (2 bars), requiring a steam turbine using about 350,000 lb/h (160,000 kg/h) steam at 900 lb/in² (60 bars). These turbines operate on a condensing cycle, but some low-pressure steam may be extracted for operation of auxiliaries, such as fans, pumps, and compressors in the utility area.

STEEL PRODUCTION

Steel is manufactured from iron—the blast furnace product—by three different methods: the basic oxygen process, the open hearth process, and the electric arc process. The objective of each is to reduce impurities; for example, the 4% carbon content of the iron is reduced to about 0.2% in the steel product, depending on the metallurgical specifications of individual orders.

Basic Oxygen Process

In the basic oxygen method, the mixture of hot metal from the blast furnace (usually 50 to 60% of the total charge), scrap steel, and slag conditioning materials, such as lime and fluorspar, are charged to the furnace (Figure 32.5). Oxygen at a rate of 15,000 to 20,000 ft³/min (425 to 566 m³/min) is injected through a lance lowered into the vessel only inches above the raw materials. The oxygen blowing period continues for 20 to 25 min to melt and burn off impurities.

A typical BOF vessel has a 100 to 300 ton (90 to 270 kkg) capacity and produces steel in about 45 min. The vessel capacity is usually filled before the blowing of oxygen to allow space for the violent reactions to occur. In the Q-BOP system the oxygen is blown through the bottom of the vessel, working through the materials and thus reducing the amount of violent splashing.

There are several water uses in the basic oxygen unit. First, the oxygen lance must be water cooled. In most plants this is a closed recirculating cooling water system. In most of these closed systems, the lance water flows through the shell side of a heat exchanger, with cooling water on the tube side of the exchanger.

Because of the high heat release, gases leaving the furnace hood during the oxygen blow are very hot. The hood is usually cooled with water recirculating through the hood panels. There are several systems where boilers are installed in the hood area for waste heat recovery and cooling of the gases.
As the gases leave the hood area, they can be further cooled by a wet scrubber and cooling system which requires large volumes of water (Figure 32.6). This water is then sent to clarifier-thickeners for sedimentation of the solids, and the water can than be recycled or discharged. There is a wide swing in water composition through the entire heat, as shown by a pH record of the effluent. Those systems not using wet gas scrubbers normally have electrostatic precipitators.

Open-Hearth Process

In the open-hearth process (Figure 32.7) the same basic materials used in the BOF process are charged to the open hearth furnace. Hot metal is not as essential to the open hearth as to the basic oxygen unit. These furnaces normally produce 100 to 600 tons (90 to 540 kkg) of steel per heat over a period of 6 to 12 h.

In the open-hearth furnaces, oxygen lance cooling is also required, similar to
FIG. 32.6 Basic oxygen furnace, showing major water uses for cooling and scrubbing. As different materials are added to the vessel during a heat, the composition of the scrubber water varies. (From EPA 440/1-74-024a, "Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Steel Making Segment of the Iron and Steel Manufacturing Point Source Category.)
FIG. 32.7 Open-hearth furnace operation, showing water used for cooling and scrubbing. (Adapted from EPA 440/1-74-024a, "Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Steel Making Segment of the Iron and Steel Manufacturing Point Source Category.")
FIG. 32.8 Electric furnace process for converting scrap to steel, showing water circuits. (Adapted from EPA 440/1-74-024a, "Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Steel Making Segment of the Iron and Steel Manufacturing Point Source Category.")
the BOF process. In addition, cooling water in the range of 750 to 1500 gal/min (2.7 to 5.4 m³/min) is required to cool the skewback channels and doors in the furnace.

Recirculating washwater from open hearth scrubbers is usually acidic so that special materials of construction are required in closing up these systems. However, because the pH of the circulated water is in the range of 2.5 to 3.0, this system can be completely closed without fear of scale. The only water loss is that present in the sludge or filter cake.

The open-hearth process has disappeared from most mills because of the high cost of providing pollution control equipment to handle the acidic dust-laden gases produced.

**Electric Furnace Process**

The third method of steel making is the electric furnace process (Figure 32.8), which can produce either the common grades of low-carbon steel, or, by charging with alloying materials, special steel such as stainless or tool steel. Electric furnaces normally operate on scrap and have the advantage of being adaptable to almost any part of the country, close to special markets. Because they are not dependent upon the hot iron from a blast furnace for their production, they are not tied down to the traditional steel centers.

Most electric arc furnaces are equipped with water-cooled doors. Water cooling is applied also to the roof ring, the electrode ring, and the electrode clamps. While most electric furnace operations use baghouses to clean their gases, there are plants using wet gas scrubbers.

**DIRECT REDUCTION PROCESSES**

As true of many developing technologies, a wide variety of processes are currently competing to determine which will be best for a newly developing market, DRI—direct reduced iron. These processes are designed to handle a wide selection of reducing agents from solids (coke, as used in the blast furnace, coal, and lignite) to liquids (oil) as well as gases (coke oven gas, reformed natural gas, and producer gas). The largest DRI production rates are from gas-fired furnaces. The charge may include the solid reductant, with supplemental fuel sometimes added, plus iron ore or pellets, and limestone or dolomite as a sulfur-reducing agent.

There are basically two furnace designs.

1. The horizontal furnace is essentially a tilted kiln (like a lime or cement kiln) with air and fuel fired into the discharge end countercurrent to the flow of solids. Air distribution to the kiln is critical to good temperature control to avoid clinker formation and poor control of carbon content of the sponge iron. Coal can be used directly as a portion of the charge and as fuel, so this type of furnace favors coal-rich nations. However, production can be increased if the secondary fuel is oil or gas instead of coal. Less than 20% of current DRI production worldwide now comes from horizontal furnaces (Figure 32.9).

2. The vertical shaft furnace (Figure 32.10) has been designed for either fixed-bed or moving-bed operation. The reductant and fuel are usually both natural gas; however, coal can be a portion of the reductant, and coal can be converted to
producer gas (coal gas), so indirectly coal could be used as both reductant and fuel. Natural gas, however, is most favorable, and it is expected that the OPEC countries will become the major DRI producers, with Venezuela already producing over one-quarter of DRI production worldwide.

The sponge iron discharged from the furnace is crushed, screened, and separated magnetically from slag and char, the latter being recovered in some versions of DRI process. The iron may be briquetted or go directly to electric furnace charging.
Water is used for cooling in a number of operations, such as recycle gas cooling and product cooling or quenching. Water is also used for gas scrubbing, and in the case of coal gas or reformer gas production, for steam generation.

**CONTINUOUS CASTING**

Continuous casting (Figure 32.11) was developed to reduce the overall cost of steel manufacturing by eliminating several steps in conventional steel preparation such as ingot teeming, soaking, and blooming. Continuous casting is the process of continuously pouring molten metal from a ladle into the complex casting equipment which distributes the liquid, shapes it, cools it, and cuts it to the desired length. The casting is continuous as long as the ladle has available metal.

![Continuous casting diagram](image)

**FIG. 32.11** Continuous casting of slabs or billets.

Should one ladle follow another without interruption, the process is called “piggy-backing a cast.”

Correct water treatment and distribution is critical to continuous casting. Steel leaving the ladle at about 2800°F (1550°C) is poured into a trough called a tundish. The bottom of the tundish has one or more openings through which the molten steel is distributed to form slabs or billets in the forming area called the mold. The mold is a water-cooled copper jacket providing for high heat exchange rates. At the start of a cast, a dummy bar is moved close to the top of the mold to completely seal the interior. As the cast starts, this bar is slowly lowered to receive molten metal, and the cooling effect of the water-jacketed mold starts the formation of a metal skin. Proceeding through the length of the mold a distance
of 30 to 36 in (1 m), the dummy bar and skin-contained metal are exposed to a series of direct-contact water sprays which complete the job of solidifying the steel. As solidification is completed, the dummy bar is cut from the formed metal and removed. The continuously moving, completely formed billet or slab then moves through guides to the straightening rolls and onto the runoff table for cutting to specific lengths.

The crucial point in this process is the copper water-cooled mold which forms the initial skin. Unless the skin is formed quickly and uniformly, a breakout will occur, shutting down the operation. The most reliable cooling water program uses the highest quality water available in a closed loop with a secondary open cooling loop. Condensate, high-purity boiler feed water, or low-hardness waters have been used as makeup. Hardness levels should never exceed 10 mg/L. Since the system is closed, there is little loss and the best corrosion inhibitors and dispersants can be used.

Spray water that contacts the billet or the slab becomes contaminated with iron oxide particles as the hot metal is oxidized. The water is normally processed in a filtration system for solids removal, recirculated through heat exchange equipment, and recycled to the sprays. The sprays must be kept from plugging at all times because the flow of water to the billet or slab being cooled must be uniform at all points.

Auxiliary mechanical equipment of the continuous casting machine is also water cooled. This may have a separate cooling water system, or it may be consolidated with the spray cooling water systems.

THE HOT-MILL ROLLING OPERATION

The hot mill (Figure 32.12) produces such products as sheets, plates, bars, rods, and structural shapes. This operation is the largest user of water in the steel mill, a reasonable use being about 7500 gal per ton of hot metal rolled (31 m³/kkg).

The first step in rolling is heating the steel billet or slab in a reheat furnace to as high as 2350°F (1300°C). Cooling water must be used to cool the doors and frames in some of the reheat furnaces, and this may be either once-through or recirculated. As the heated billet or slab leaves the furnace, high-pressure descaling water up to 2000 lb/in² (135 bars) is blasted onto the surface to remove any oxide scale so that no imperfections are caused by rolling this debris into the metal.

Water is also used for roll cooling and for spraying directly onto the steel prior to its being handled at the end of the machine. A high-speed sheet mill operates in the range of 4000 to 6000 ft/min (1220 to 1830 m/min); a high-speed rod or wire mill operates at 8000 to 9000 ft/min (2440 to 2750 m/min). As water passes over the hot metal from rolling station to rolling station, the oxides washed from the metal are carried to a scale pit. There is a wide particle size range in the operation of descaling as the slab or billet is going through the mill. Larger particles are removed during the initial rolling (the roughing end), and very fine particles are washed off in the final rolling operations (the finishing end).

Much of the scale encountered in the scale pit can be removed with clam-type diggers, electromagnets, or traveling screen grates, but the fine-sized particles are normally separated by coagulation in water clarification equipment. Most new plants recycle the water used on the hot strip mills (Figure 32.13).

When the water is recycled through the mill, attention must be given to potential problems of scale, corrosion, fouling, and microbial activity. This is especially
FIG. 32.12 Hot mill rolling plate for further reduction through a hot strip mill. (Courtesy of Tippins Machinery Company, Inc.)

FIG. 32.13 Hot strip mill, showing recycle of clarified water for roll cooling and scale removal.
FIG. 32.14 Cold rolling mill with recirculated water containing rolling oil emulsion. Provision is made for periodic treatment of spent rolling oil emulsions.
true for water going to the high-pressure sprays. Heat removal may be required for controlling the work environment.

Considerable amounts of water are used for cooling electric motor systems in many of these mills. The motor-driven rolls keep the product moving to its end point. There can be as many as 300 to 400 motors at an installation.

**COLD ROLLING MILLS**

Cold rolling mills are divided into two categories: single stand and multistand, where steel is rolled in tandem. Because the steel is cold, it is hard to work, so the cold rolling requires lubricant in water (soluble oil) not only to cool, but to give a good finish to the steel. Water properties to be controlled in this operation include total suspended solids, iron, and oil. There are two systems for feeding lubricant and water in a cold rolling operation: recirculating and once-through.

**Recirculating System**

In the recirculating system a weak emulsion of oil and water circulates to the roll for cooling and lubrication of the sheet, collects under the roll, and passes through the treatment process. The emulsion is carried from the first stand to the second, third, and fourth. Fresh water is used only on the first and last stands. The spent liquid is normally collected, and an emulsion breaker is used to free the oil. The solids are settled and reclaimed for the iron content, and the oil is reclaimed and reused (Figure 32.14).

Water treatment for these systems consists of sedimentation, flocculation, filtration, and air flotation. The flows from these operations vary from 200 to 1500 gal per ton of steel processed (0.8 to 6 m$^3$/kkg).

**Once-through System**

Another cold rolling operation using direct application of oil is the once-through system, used on thin gauge material such as tin plate. The usual treatment system serves a multistand mill, having two to five stands. A 5 to 10% oil-in-water emulsion is applied to the steel at the first four stands, while a detergent solution is applied at the last stand. A once-through system is used for this service since the water must be kept clear. The wastewater, which contains a significant amount of oil, goes to a treatment system that includes an air flotation unit with oil skimmer, chemical treatment, aeration tanks, flocculating tank, and a settling basin or a clarifier.

Emulsion breaking chemicals may be required for efficient treatment of this waste. The oil is reclaimed and reused, while the sludge is disposed of as landfill.

**HEAT TREATMENT**

To produce special physical properties in certain grades of steel, the metal passes through a series of heat treatment operations including heating in a furnace,
FIG. 32.15  Schematic of sinter plant showing wet and dry dust collection. (From EPA 440/1-74-024a, "Developing Document for Effluent Limitation Guidelines and New Source Performance Standards for the Steel Making Segment of the Iron and Steel Manufacturing Point Source Category.")
annealing at a carefully controlled temperature for a specified period of time, quenching in water or oil, and final cooling in air.

Generally, the temperatures in the annealing furnaces are not so high as to require water cooling of the furnace elements, but some cooling may be needed in special cases. The temperature of the quench oil or water quenching tank must be carefully controlled, so the coolant in the quench tank is usually recirculated through a heat exchanger to remove the heat brought into the system from hot metal. Oil discharge, such as could arise by overflowing the quench oil system or by rupture of a tube in the oil-water heat exchanger, must be guarded against. Oil is generally the only likely contaminant in the heat treatment area.

**SINTERING**

Sintering is a process that recovers solid residues from scrubbers and clarifiers. This process includes collection of useful materials such as iron ore fines, mill scale, limestone, flue dust, and coke fines (Figure 32.15).

The various materials are mixed in controlled proportions with a fixed amount of moisture then distributed onto a permeable grate and passed through to an oil-or gas-fired furnace (ignition furnace). Combustion air is drawn downward through the bed. After a short ignition period the firing of the bed surface is discontinued, and a narrow combustion zone moves downward through the bed, with each layer in turn heating to 2200 to 2250°F (1204 to 1228°C). In advance of the combustion zone, moisture and volatiles vaporize. In the combustion zone bonding of the particles occurs, and a strong agglomerate is formed.

Most of the heat from the combustion zone is absorbed by drying, calcining, and preheating the lower layers of the bed. When the combustion zone reaches the base of the sinter mix, the process is complete. The sinter cake is tipped from the grate and broken up. After screening, the undersize is recycled, and the remaining sinter is sent to the blast furnace.

Water is added to the sinter mix, to control moisture at 5 to 8%. Water is also sprayed for dust control in the plant, and at the many conveyor transfer points where raw materials are moved from storage areas to the sinter line (strand).

Many plants scrub the sinter furnace exhaust gases to remove entrained solids. The scrubber water usually requires treatment by coagulation to remove suspended solids; chemical conditioning to control scale, corrosion, and fouling; and removal of pollutants prior to discharge.

**ACID PICKLING**

The treatment of steel in an acid bath, known as pickling (Figure 32.16), removes oxide from the metal surface and produces a bright steel stripped down to bare metal and suitable for finishing operations, such as plating, galvanizing, or coating. Both sulfuric and hydrochloric acids are used, with the latter growing in popularity as more by-product hydrochloric acid becomes available from the chemical industry. With either acid, disposal of spent pickle liquor is a serious problem.

Pickling may be either batch or continuous. Usually, the acid is prepared at about 5 to 15% strength, depending upon the work to be processed in the pickle tank and the type of acid used for pickling. As the acid works on the oxide surface,
there is a gradual buildup of iron in the pickle solution and a depletion of the acid. When the iron content reaches a level that slows the pickling operation, the bath is either dumped or reprocessed. In some pickling operations, acid is continually withdrawn in order to hold a fairly constant ratio of iron to free acid in the pickle bath, thereby maintaining uniform pickling conditions for all the steel passing through. The metal leaving the pickle bath carries some of the liquor with it into the subsequent rinsing and neutralizing operations. The loss of acid by dragout varies with the type of work, the shape of the products being pickled, and the speed of the operation. It can run as high as 20% of the acid used. Appreciable rinse water must be put into the rinse tank and withdrawn continuously for discharge to a treatment facility.

**SLAG PLANT**

Various useful products are recovered from slag, some being produced from the slag in a molten form, and others after solidification.

Molten blast furnace slag can be quenched with water to produce lightweight expanded aggregate for the manufacture of cinder block. It can also be spun into mineral wool insulation. Solid air-cooled slag is crushed to various sizes for use as a track ballast, highway foundation, and similar structural material.

In plants handling slag there is normally airborne dust that tends to cake on conveyor belts or interfere with proper operation of mechanical equipment. Water washing of the air is sometimes practiced, or water may be used for washing conveyor belting, creating a high suspended solids wastewater.

BOF, open-hearth, and electric furnace slags are very high in iron. Therefore, they are usually broken up and reclaimed for charging to the blast furnace.
UTILITIES

Because of the useful combustible gases produced at the coke ovens and the blast furnaces, steel mills are able to produce a large percentage of their total power requirements by burning this fuel in boiler houses. In addition to boilers directly fired with these by-product fuels, other boilers reclaim heat from gases discharged from the open-hearth furnaces, the BOF shop, and the engines that operate on coke-oven gas.

The steam generated by these boilers is used throughout the complex for driving turbines, powering presses and forges, and providing heat wherever it may be required. Some of this steam may be treated with steam cylinder oil ahead of steam engines and presses, producing an oily condensate that requires treatment prior to disposal.

In addition to production of power from steam, some by-product gases are used in gas engines to produce electric power or mechanical energy directly for such uses as compressing air for the blast furnaces. Other utilities include air compressors, vacuum pumps, and pump stations to supply the enormous quantities of air and water needed for the operation.

The water requirements for these utilities in the steel mill are similar to those of other industries. High-quality water must be produced for makeup to the steam generators, and these in turn concentrate the water, which is then removed by blowdown at a relatively high salinity level. The water treatment facilities required for producing this high-quality water generate their own wastes, such as lime sludge from lime softening operations, brine from zeolite softening operations, or spent acid and caustic from demineralizer regeneration.

Cooling water is used by these utilities for such purposes as condensing turbine exhaust, cooling compressor jackets, cooling bearings on various types of powerhouse auxiliaries, and conveying ashes from coal-fired furnaces.

SUGGESTED READING