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WATER SUPPLY, RE-USE AND DISPOSAL AT AN INTEGRATED IRON AND STEEL WORKS IN GREAT BRITAIN 1/

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1/ The views and opinions expressed in this paper are those of the author and do not necessarily reflect the views of the secretariat of UNIDO. The document is presented as submitted by the author, without re-editing.

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INTRODUCTION

To produce one ton of steel in an integrated works requires approximately two hundred tons of water. About one third is used for cooling furnaces and one third for cooling condensers on steam-driven turbo-blowers and generators. The remainder is used for cooling gases and rolling mills, quenching hot materials, the removal and conveyance of solids to central collecting and disposal points, for steam raising and hygiene and amenity purposes.

Table I gives typical quantities used in the various processes of manufacture.

Table I. Typical quantities of water used in the various processes of iron and steel manufacture

Coke making	4,500 gal/ton coke
Condenser cooling (blowers and generators)	16,000 gal/ton iron
Blast furnace cooling . . .	10,750 gal/ton iron
Blast furnace gas cleaning	5,000 gal/ton iron
Open hearth steel making .	4,500 gal/ton crude steel
Continuous casting of steel	1,250 gal/ton crude steel
Rolling mills	5,000 gal/ton crude steel
Steam raising	250 gal/ton crude steel

Whilst the water is used in a variety of ways the actual consumption amounts to not more than about five tons per ton of steel produced, the bulk of it being lost as vapour into the atmosphere. As far as the water resources of a particular area are concerned this consumption may in effect be increased many times by discharge of clean or lightly contaminated waters direct to the sea, river estuaries or highly polluted inland waters.

The conservation of water, disposal of effluents and prevention of pollution go hand in hand and should therefore be viewed as a common problem.

For more than a decade such a view has been held at the Appleby-Frodingham works of the United Steel Companies Limited, now part of the Midland Group of the British Steel Corporation. Since Appleby-Frodingham is a fairly large integrated works it is thought that some of the problems met there and the methods adopted to overcome them may apply to other plants, particularly those where recirculation of water is a necessity.

The works are situated at Scunthorpe in the county of Lincolnshire, approximately eight miles south of the Humber and four miles east of the river Trent.

The history of Appleby-Frodingham goes back just over one hundred years and its development has been one of continual modernisation and expansion around what were originally three separate works.

Although the iron- and steel-making processes are fully integrated and the plant is modern, this type of development has inevitably resulted in de-centralised water distribution systems. In order to get these distribution systems into perspective it should be noted that the works covers an area of more than 1,200 acres and the annual steel production is in excess of one and three-quarters of a million ingot tons.

FRESH WATER SERVICES

Overall Balance of Supply and Usage

The sources of supply are between two and a half and five miles from the works. This, coupled with the fact that the quantities which can be extracted are limited, determines the use of recirculating cooling systems and the pursuance of a continued policy of water conservation.

The sources of fresh water drawn upon by the works are capable of producing an assured supply at the rate of 3,550 gallons per minute and the average demand made upon them amounts to approximately 70% of that figure.

Nearly 90% of the water brought into the plant is eventually lost as vapour into the atmosphere. The remainder is discharged with some surface drainage and process liquids via a small stream to the river Trent.

Arrangements are continually being made to permit maximum re-use of the water and to recover plant drainage and rainfall to supplement the sources of supply. By this means the intake of fresh water has beeh reduced to just below four tons per ton of steel ingots produced.

Details of the supply and usage for the year ending March 1967 are shown in Fig. 1.

<u>Sources of Supply</u>

There are three main sources of supply:

(1) the river Ancholme;
(2) effluent from the Scunthorpe sewage works - referred to as the Ashby Ville supply;
(3) borehole water - known as the North Lincoln supply.

The Ancholme river is a large land drain which discharges into the Humber estuary. The pumping station, situated on the bank approximately six miles from the mouth of the river, is capable of delivering up to 1,500 gallons per minute through a 14" pipeline into the works distribution network, a distance of approximately four and a half miles.

The effluent from the Scunthorpe Corporation is taken from the outlet discharge channel of the sewage purification works, through a venturi flume-measuring device, into a shallow lagoon of 2.3 million gallons capacity situated in the disused Ashby Ville ore mines. A pumping system capable of handling up to 2,000 gallons per minute delivers this water to the works through two and a half miles of 15" diameter cast iron main.

An electrically-operated sluice gate situated in the side of the outlet channel at the sewage works permits quantities up to the normal dry weather flow of effluent to be taken without causing interference in the operation of the sewage works themselves. Three identical pumps, two working and one stand-by, are installed in the pumphouse. They are designed and interconnected to operate with a good degree of efficiency when called upon to deliver any desired quantity between 800 and 1,800 gallons per minute through the 15" pipeline without causing a variation in pressure of more than 6 lb/in^2 at the water treatment plant on the works.

The operation of the pumphouse is remotely controlled from the water treatment plant by telecommunication equipment linked by a telephone cable. In addition to control of the sluice gate at the off-take from the sewage works and the necessary items in the pumphouse, the equipment gives information at the water treatment plant on rates of flow and water levels obtaining at the pumping station.

The North Lincoln boreholes are located four miles from the works and are sunk into the Ponton limestone which extends from 117 to 140 feet below ground level. The water is pumped from a level normally varying between 60 and 110 feet below ground, dependent upon the rainfall during the previous quarter of the year, into a collecting sump near the pumphouse. From there it is delivered through a 12"/14" diameter pipeline direct to the works.

Quality of Supplies

Typical analyses of the raw water supplies are given in table II.

Table II. **Typical analyses of raw water supplies**
(except for pH values, results are expressed in parts per million - p.p.m.)

Constituent	Ancholme	Ashby Ville	North Lincoln
Suspended solids	14	15	<3
Total dissolved solids . .	700	850	650
Chlorides as Cl	44	90	40
Alkaline hardness as $CaCO_3$	180	160	240
Non-alkaline hardness as $CaCO_3$	280	150	240
Total hardness as $CaCO_3$ . .	460	310	480
Calcium hardness as $CaCO_3$.	420	270	450
Ammoniacal nitrogen as N_2 .	0.1	2.0	nil
Nitrate nitrogen as N_2 . .	3.0	22.0	trace
Permanganate value	3.0	9.0	0.3
Free chlorine as Cl	nil	nil	0.04
Phosphate as PO_4	trace	14.0	nil
Detergent as Manoxol O.T. .	0.3	4.0	nil
pH value	7.8	7.6	7.7

Since the Ancholme river is a large land drain, the quality of the water is subject to seasonal variations. Whilst the total hardness normally varies between 400 and 500 p.p.m. as $CaCO_3$, and the chlorides between 40 and 350 p.p.m. as Cl, during prolonged periods of dry weather the concentrations have been known to rise as high as 1,200 and 1,500 p.p.m. respectively. After periods of heavy rain or winter thaws the water contains appreciable quantities of colloidal matter derived from the land. In common with many other similar rivers throughout the country, in the last decade the effluent discharged from sewage treatment plant installed to serve rural areas has formed an increasing percentage of the total flow of the rivers.

The Ashby Ville supply, whilst being a fairly good quality sewage effluent, contains organic matter, phosphate, synthetic detergents etc. which present various problems, e.g. foaming, when using the water on the plant. It tends to be more consistent in its quality than the river water and this, together with the fact that it is an assured source of supply not very far from the works, largely compensates for any extra cost and difficulty encountered in treatment and usage.

As may be seen from the analysis the North Lincoln water, although very hard, is free from organic matter and other constituents which would make it unsuitable as a source of supply for drinking, hygiene and steam-raising purposes.

Distribution

On the works there are two completely separate distribution systems, one for the Ancholme and Ashby Ville waters and one for the North Lincoln borehole water. Whilst for some consumers North Lincoln water is held as stand-by for Ancholme/Ashby Ville water and vice versa, to avoid any possible contamination of the drinking supplies, at no point are the two systems directly connected. Where automatic changeover is required it is accomplished by means of open discharges from the two mains controlled by float valves set at different levels into a tank subjected only to atmospheric pressure. In all other cases quick manual changeover can be effected.

An electrical interconnection between the Ancholme and North Lincoln pumphouses, one of which is normally fed with power from the grid and the other from the works generating system, provides both with an alternative electrical supply and helps to ensure continuity in the supply of water.

A reservoir holding approximately twelve million gallons of Ancholme water is located at the works to provide cover for a failure of one or both of the Ancholme and Ashby Ville supplies resulting from a fractured main or other mechanical fault. Pumps, remotely controlled from the ironworks water treatment plant, are capable of delivering the full requirements of Ancholme and Ashby Ville water into the distribution mains.

Temporary failures of the North Lincoln supply, such as may be caused by a fractured pipeline, are covered by strategic connections with the Scunthorpe Corporation mains to ensure the continuity of the drinking and amenity supplies and by adequate storage capacity of the treated water for steam-raising consumers.

A ring main system of distribution has been gradually developed. Trunk mains and stop valves are so arranged that should a failure of the pipe occur, the section can be quickly isolated and supplies maintained through an alternative route. To allow this operation to be carried out as quickly and smoothly as possible, each valve on the trunk mains and primary branch mains is given a number corresponding to that shown on the diagrammatic layout of the distribution system. Copies of the latter are available in all pumphouses, treatment plants and buildings housing personnel concerned in the operation and maintenance of the general water services. The number of the valve and the necessary instructions for operating it are cast on the valve pit cover, which is made to a standard pattern, easily recognisable by those concerned and capable of being lifted by one man.

Utilisation

The Ancholme water is used in its raw state as make-up to coke-quenching, gas-cooling and rolling-mill systems and for general plant cleanliness. After removal of the alkaline hardness it is used to replenish the cooling systems of blast furnaces, melting furnaces, continuous casting plant, etc.

Ashby Ville water is used without treatment as make-up into the blast furnace gas-cleaning system and, after lime softening, to replenish the losses from the turbo-blower and coke-oven-cooling recirculating systems. Fig. 2 is a flow diagram showing the average usage of this sewage effluent source of supply over the past few years.

North Lincoln water is used for hygiene and amenity purposes throughout the works and, after softening, as feed-water for boilers and evaporative cooling systems, either direct or via evaporators.

When the quality of a water becomes unsuitable for its own particular circuit, for example because of the concentration of normally soluble salts causing danger of their precipitation, it is bled off where possible into a system where a lower-quality water is acceptable. Only when recovery is uneconomical because of location or unduly poor quality is the water allowed to enter the drainage system. Over the last fifteen years arrangements have progressively been made to collect the drainage from the works and use it for such purposes as sinter mixing and quenching, slag processing and coke quenching.

Treatment

It can be seen from table II that water from all three sources of supply has a high hardness content.

The alkaline hardness of the Ancholme river water is removed with lime before feeding it as make-up into recirculating cooling systems.

The Ashby Ville water is shock-dosed with chlorine as it enters the delivery main to the works at the rate of 10 p.p.m. for 90 minutes every 12 hours to inhibit the growth of slimes and algae. At the water treatment plant conventional lime-softening with sludge recirculation is practised which increases the clarity and reduces the hardness, suspended solids, organic matter and phosphate content of the water before it is fed as make-up into the cooling systems..

The whole of the North Lincoln supply is chlorinated at source so that a free residual chlorine content of not more than 0.1 p.p.m. is maintained in the distribution mains on the works. That used for steam-raising purposes is subsequently lime/soda softened, followed by base exchange treatment to reduce the residual hardness to commercial zero. The softened water is used direct as feedwater to the lower-pressure steam-raising boilers but, in the case of the 450 lb/in^2-pressure boilers, it is fed to four triple-effect thermo-compression -type evaporators for conversion into distillate.

Just over 60% of the make-up water required by the works is now softened before use in two water treatment plants, one located at the ironworks and one at the steelworks.

Fig. 3 shows the dimensions of a typical precipitation-type softener installed at those plants and the results obtained when dealing with either river water or sewage effluent.

The wastes to be disposed of from the softening plants result from the backwashing of the filters and the precipitation of the solids in the form of sludge.

Each filter requires backwashing at least once every twenty-four hours at a rate of 550 to 650 gallons per minute of water for a period of ten minutes. There is a total of twenty-five filters which require an average continuous flow of roughly one hundred gallons per minute. This, in addition to the loss of water, could constitute a source of pollution in that the suspended solids content is in the region of 1,000 p.p.m., the pH value is high and it may contain an appreciable amount of organic matter, particularly from the filters dealing with sewage effluent. None of this backwash water is put to drain. It is discharged into settling pits where the solids are allowed to settle and the supernatant liquor decanted and returned to the softener or used as make-up in a system in which its quality will not prove detrimental.

The equivalent of forty tons of dry solids is removed from the water in the reaction and sedimentation tanks of the softening units each week. It is run out of the tanks as a sludge containing 5 to 12% of dry solids on a weight basis and it is dealt with in a similar manner to the filter backwashing discharge. At each plant the size of the settling pit is determined by the volume of backwash water or sludge discharged from the softeners, the rate at which the solids settle to permit reclaiming of the water, and the frequency with which settled solids are removed for disposal. A programme of staggered times for backwashing individual filters of a battery, and sludging reaction and sedimentation tanks, is adopted to limit the size of the necessary settling pits.

At the steelworks softening plant the sludge containing 20 to 25% of solids on a weight basis is extracted from the settling pit by vacuum rail tank and transferred to the pig-casting plant where it is used for spraying the moulds. If it is not required by that plant it is transferred to the works sludge drying pond on the slag tip. The sludge from the settling pit at the ironworks softening plant is pumped along with the solids extracted from the blast furnace gas-cleaning water into the same sludge-drying pond.

RECIRCULATING COOLING SYSTEMS

As previously stated, cooling water is recirculated, each system having its own cooling tower or towers. While the losses by evaporation from the towers vary with the temperature rise of the water in each particular cooling system, the average is about 1.25% of the water in circulation. Owing to this evaporation it is necessary to bleed off a portion of the circulating water to maintain the concentration of calcium sulphate below the level at which sulphate scale will form in the cooling elements. The minimum amount of bleed-off necessary to ensure a safe working margin with the type of make-up water used is 18% of the quantity of water lost as vapour into the atmosphere from the cooling tower. The total fresh water make-up therefore amounts to about 1½% of the volume in circulation.

Twenty-nine separate cooling systems with a total flow of approximately one hundred and twenty thousand gallons per minute are in use on the works. They can conveniently be divided into two main groups -

(1) Straightforward systems in which the water is used only to remove heat, referred to as Indirect Cooling Systems, e.g. those serving condensers, furnace elements, compressors, oil coolers, etc.

(2) Combined cooling and cleansing systems, e.g. those used in gas cleaning, rolling mills and continuous casting plants, referred to as Direct Cooling Systems.

Indirect Cooling Systems

About two thirds of the water used in the works is contained in this type of system. Their main purpose is to provide a continuous supply of water of suitable quality to ensure efficient cooling of production equipment. Certain items of equipment necessary in these systems, e.g. pumps, reservoirs, balance and emergency reserve tanks and cooling towers are common to both groups listed above. To avoid repetition the following comments on those items therefore apply to both groups.

Pumps

There is a total of 290 electrically-driven centrifugal pumps with capacities ranging from 50 to 6,000 gallons per minute to circulate water round the various systems. An average of 160 is in use at any one time, the remainder being provided as stand-by units or for use in an emergency, e.g. during storms.

Most of the pumps are to be found in eight main pumphouses:

two at the ironworks;
one at the coke ovens;
one at each of the two melting shops;
one at each of the three rolling mills.

A view of the inside of one ironworks' pumphouse is shown in Fig. 4.

While the delivery pressures of the pumps vary from circuit to circuit, the average head is of the order of one hundred feet of water. Practically all units are designed to operate at 75 to 80% efficiency when handling their rated volume and at this level of operation the total horsepower absorbed is slightly more than ten thousand. It should be borne in mind that a large number of the items of plant, e.g. blast furnaces, require spray or open-discharge cooling, thereby necessitating double pumping of the water in systems which include atmospheric cooling towers.

Where pumps are handling water containing abrasive solids in suspension, such as rolling mill scale, impellers and casings are looked upon as expendable after about one and two years life respectively. On clean water the bronze impellers and cast-iron casings have normal lives of approximately ten years and more than twenty years respectively.

Reservoirs

Each cooling system includes its own reserve of water in a sump or reservoir generally incorporated in the foundation structure of the cooling tower. The reservoir normally has a capacity of at least equal to the water contents of the circulating system, together with sufficient margin to cater for losses by evaporation etc. for a period of at least four hours should no make-up water be available. To keep out sunlight and thereby discourage the growth of algae in the water, the reservoirs are normally covered with a concrete tray. There is no doubt that this is a major factor contributing to the negligible demand for chemical treatment to prevent organic growths in the cooling systems, particularly in those using sewage effluent as make-up water.

Balance and emergency supply tanks

In order to maintain a relatively steady pressure with fairly wide fluctuations in water demand and to provide an emergency supply in case of temporary failure of the electric power to the pumps, overhead balance and reserve tanks are included in all systems where interruption of the flow of water would result in failure of equipment, for example in furnace cooling systems, or the creation of a hazard, for example in blast furnace gas-cleaning systems. The tanks range in capacity from about fifteen thousand to two hundred and fifty thousand gallons, dependent upon the volume of water circulating in the system, and are installed at heights of between forty and one hundred and seventy-five feet above site level. They are designed to provide approximately twenty-five minutes reserve at normal flow.

Such a system of reserve suffers from a number of disadvantages. It involves a high capital cost for an installation that is used infrequently and for relatively short periods; the reserve time is limited and, following a power failure, the system cannot be considered safe until the depleted tank has been replenished. Since replenishment must be made from the fresh-water supplies, several hours may elapse before the water in the tanks is back to normal working level, especially if a number of systems have been simultaneously affected by the power failure. Moreover, facilities for the handling and disposal of the large volumes of stored water suddenly discharged to drain create further problems and expense. It is essential however to make available some alternative to the normal pumped supply. The use of diesel-driven stand-by pumps, automatically brought into service when a reduction in water supply pressure occurs, is a better and much less costly proposition than the provision of large reserves in high-level tanks.

A combination of small-capacity overhead tanks and diesel-driven pumps is considered to be the most satisfactory and economical overall solution. The tanks would act as "balance" for the systems and provide about two minutes reserve in order to give the diesel-driven pumps ample time to run up to full load.

Cooling towers

A total of twenty-six atmospheric cooling towers with heat removal capacities ranging from about one hundred to three thousand seven hundred therms per hour are installed. The majority of them are designed to cool water from around 95°F to 75°F when the atmospheric wet-bulb temperature is 60°F. Nine are natural draught chimney towers and the remaining seventeen are mechanical draught towers. Twelve of the latter employ induced draught and five are of the forced-draught type.

Fig. 5 is a photograph of the natural draught tower cooling the water for the turbo-blower condensers and two of the blast furnaces. Details of this tower, which is the largest on the works, are: height 265 feet; diameter 183 feet; water flow 2.28 million gallons per hour; heat removal capacity 3,720 therms per hour; height of water inlet above cill level 30 feet.

Practically all the towers are packed with triangular timber laths or film-flow timber grids. The former packing is designed to encourage the falling water to break up into droplets, while in the latter, droplets are discouraged and the water is caused to spread thinly over the surface of the filling.

In the lath-filled towers the majority of the water distribution systems are of the "flume" type. This type consists essentially of a series of troughs arranged symmetrically across the tower at water inlet level. The water passes through holes drilled in the bottom of the troughs on to splash plates about two feet below, where it is broken up into droplets before falling on to the timber laths.

In a natural draught tower the pressure difference of the atmospheric air as a result of chimney height, the temperature rise of the air heated by the water and the wind velocity differentials all combine to create the draught through the tower.

For relatively small water loads the height of the chimney necessary to produce the draught results in a high capital cost per thousand gallons per minute of water to be cooled compared with mechanical draught towers.

In mechanical draught towers, fans which are an integral part of the structure are used either to force or induce the air through the tower. This gives close control over the quantity and velocity of the air. More packing per unit volume of tower may be included than in the case of the natural draught installation and a longer cooling range and closer approach to atmospheric temperature for the recooled water are possible.

The capital costs are appreciably lower than those for an equivalent-duty natural draught tower but the operating costs are higher because of the power used by the fans and the need for more maintenance.

It is not easy to define when a natural draught tower is economically preferable to a mechanical draught unit since the required duty, expected operating life and site conditions all influence the decision. With a reasonably light cooling duty, e.g. cooling from 100°F to 90°F at an atmospheric wet-bulb temperature of 60°F, the total costs of both types for cooling a quantity of four thousand gallons per minute are similar if capital depreciation is allowed at 10% per annum. As the quantity decreases below four thousand gallons per minute the balance is increasingly in favour of mechanical draught whereas increases in quantity above four thousand increasingly favour the adoption of natural draught towers.

At the continuous casting plant where a pressurized cooler offers certain operational advantages over the atmospheric type of tower and a recooled water temperature of the order of 130°F can be tolerated, an air-cooled heat exchanger has been installed for dealing with the water used for spray cooling of the hot steel blooms. A comparison of the capital and running costs based on an operating time of eight thousand hours per annum is given in table III.

Table III. Cost comparison for evaporative cooling tower and air/water heat exchanger

Duty: to cool 2,400 gal/min of water from 143.5 to 130°F with atmospheric temperature of 60°F wet bulb, 65°F dry bulb

	Induced draught evaporative cooling tower Annual cost £	Finned-tube air/water heat exchanger Annual cost £
Amortisation - 10% of capital cost .	400	1,350
Electric power at 1.0 pence/kWh: fans	(average 7½ hp) 190	(average 60 hp) 1,500
pumping water through cooler	15 ft head loss 370	23 ft head loss 570
Maintenance	350	500
Replacement of water losses*	)1s.6d. per)1,000 gal 1,380	negligible
Total	2,690	3,920

*Including bleed-off, losses amount to 150 lb of water per therm of heat dissipated. (1 therm = 100,000 B.t.u.)

The heat exchanger has the advantage over the atmospheric tower in that the quality of the water in circulation can be maintained at a high level with simple treatment since contamination by dust and fume in the air used to effect the cooling is avoided. The absence of vapour discharge into the atmosphere may also be of benefit where the cooling is carried out in the proximity of other plant items. It is evident however that where these benefits are not material the cost of the fresh water, including treatment, would have to rise to almost three shillings per thousand gallons before the increased capital and running costs of such a cooling unit were offset.

As shown in table IV the total heat removed by cooling towers on the works is of the order of eight thousand two hundred and fifty therms per hour, which is equivalent to the heat content of approximately seven hundred thousand pounds of steam at a pressure of 200 lb/in^2. The incentives therefore for development of suitable means of eliminating such a wastage of heat, e.g. by the use of evaporating cooling systems, are by no means small.

Table IV. Heat dissipated by cooling towers in the main water recirculating systems

	Heat dissipated therm/h
Sinter plants	140
Blast furnace cooling	1,250
Blast furnace gas cleaning	1,230
Turbo-blower condensers	2,000
Coke ovens	1,250
Melting shops (including continuous casting plant)	1,430
Oxygen plant	100
Rolling mills	330
Electrical power generation	520
Total	8,250

If the cooling water is recycled under pressure without dissipation of its heat by a cooling tower or heat exchanger some of it will be converted into steam which can be separated from the water and fed into the steam distribution system. This method, known as evaporative cooling, may be applied to furnaces etc. where cooling at relatively high temperatures and pressures is permissible.

There are four such installations on the works, three on open-hearth steel furnaces and one at the rod/bar mill bloom reheater. Fig. 6 is a simplified diagrammatic arrangement of the installation on an open-hearth furnace. Units which are evaporatively cooled include the door arch plates, furnace chills, fuel burners and tuyeres. Water cooling has been retained on the oxygen lances and doors.

About four hundred and eighty gallons per minute of boiler water is circulated through the cooling units, in the proportions shown in table V, by one of a range of three pumps. Two of these are electrically driven and one is normally in use. Should a pump fail because of mechanical or electrical causes, a steam turbine-driven pump is automatically brought into service.

Table V. Water supplies to evaporatively-cooled elements on an open-hearth furnace

	Water supply, gals/min
Arch plates	270
Furnace chills	40
Burners	132
Burner tuyeres	40
Total	482

Individual branches in the circuit are arranged so that they are roughly the same length and restricting orifices are inserted to balance the water flow to the cooling units. In the event of a break in a cooling unit or its associated pipework, these restricting orifices prevent the loss of an excessive amount of water, by severe throttling of the flow by steam which is flashed off from the water as the pressure falls. At the same time, non-return valves in the outlet pipes prevent feedback from the other cooling elements.

The adoption of evaporative cooling at these furnaces has resulted in a steam credit of about three thousand pounds (lb) per hour per furnace and has avoided the necessity of investing a large amount of capital on extending the conventional water-cooling system to cope with the increased demand of the furnaces. At the rod/bar mill bloom reheater the amount of steam produced from the furnace skids is of the order of seven thousand pounds per hour.

Although it is initially more expensive than conventional water cooling, in addition to the steam credits already mentioned, evaporative cooling makes a significant contribution towards economy in the use of water on the works.

Treatment of water in indirect cooling recirculating systems

As previously stated, lime-softened river water or sewage effluent is used as make-up in the systems. The calcium carbonate that remains in solution in the softened water is concentrated by the evaporation in the cooling tower with the result that the most common problem is that of preventing the formation of calcium carbonate scale in the cooling elements. This is achieved by the addition of acid and dispersants or inhibitors to the circulating water. As an example, elimination of scale deposits in the turbo-blower condenser cooling system which uses lime-softened sewage effluent as make-up has been achieved by the use of sulphuric acid to limit the carbonate alkalinity to not more than seventy parts per million, and the addition of sodium hexametaphosphate to maintain a metaphosphate reserve of approximately half a part per million in the circulating water. The cost of the treatment amounts to slightly less than one fiftieth of a penny per thousand gallons of water circulated.

As stated earlier, in order to prevent the formation of calcium sulphate scale in the cooling elements, the minimum amount of bleed-off is 18% of the quantity of water lost as vapour from the cooling tower to the atmosphere. Wherever possible, such bleed-off is used for quenching or processing where water of a poorer quality is not detrimental. Examples of this can be seen in Fig. 2. Whilst in many instances the bleed-off does not constitute an effluent problem, since it would not cause pollution of a river, its re-use results in a reduction in both the quantity of waste water leaving the works and the quantity of incoming fresh water.

Direct Cooling Systems

In these systems the water comes into direct contact with the substance being cooled and, in addition to absorbing heat, invariably acts as a carrier of solids originating in the process. There are seven such major systems on the works serving gas-cleaning plants, rolling mills, pig-iron casting machines and plant for continuous casting of steel blooms. To ensure efficient operation of the cooling system as a whole it is necessary to remove the solids from the water before it is recycled. The equipment generally provided on the works for this purpose includes clarifiers, hydrocyclones and filters. It is proposed therefore to describe the water system installed at one of the blast-furnace gas-cleaning plants, which includes clarifers, and that provided at the section-rolling mills which includes hydrocyclones and sand pressure filters.

Water system for blast-furnace gas cleaning.

The water used for cooling and cleaning the gas from the blast furnaces comes into direct contact with the gas in the washing towers and electrostatic precipitators. About twenty-eight gallons of water is used for each thousand cubic feet of gas cleaned. The water is subject to a rise in temperature of about 12°F and an increase in both suspended and dissolved solids content during its passage through the gas-cleaning equipment. The suspended solids content of the water leaving the gas plant generally varies between two hundred and fifty and five hundred parts per million under present conditions of operation, although values of up to three thousand parts per million have been occasionally encountered.

Fig. 7 is a flow diagram of the water system provided for dealing with the gas from two of the blast furnaces. The water is clarified before cooling and recirculation in three hundred-foot diameter clariflocculators, two of which can be seen in the foreground in Fig. 5 These consist of cylindrical concrete tanks similar to a conventional thickener but, in addition to having slowly revolving rakes for moving the settled solids to a central discharge cone, are equipped with a central flocculating mechanism. The feed enters the clariflocculator through a flocculation compartment in which paddles bring the particles into contact with each other under controlled conditions and cause them to agglomerate. The effect of this is to minimize the amount of fines in the overflow and thus improve clarity. A suspended solids content of twenty to forty parts per million in the overflow water is normally obtained without the use of chemicals to promote flocculation. The underflow sludge is withdrawn with not more than 10% by weight solids and pumped through almost three thousand feet of three inch diameter mild steel pipeline into a drying pond on a slag tip located in a worked-out section of the ore mines.

The impurities dissolved in the water used in the gas-cleaning process vary greatly with the type of burden used in the blast furnace. A typical analysis of the circulating water is shown in table VI. While these levels of impurities are present because the water has been recycled many times, even if the water were passed only once round the circuit the extent of the presence of cyanide, zinc and lead would make the water toxic and unsuitable for discharge into a clean river.

Table VI. Typical analysis of water in blast-furnace gas-cleaning circulating system

	p.p.m.
Suspended solids	35
Total dissolved solids	9,500
Total hardness as $CaCO_3$	450
Alkalinity to phenolphthalein as $CaCO_3$	250
Total alkalinity as $CaCO_3$	2,400
Chlorides as Cl	1,100
Cyanides as CN	30
Zinc (dissolved) as Zn	40
Lead as Pb	5
pH value = 8.4	

As shown in Fig. 2, an average of one hundred and fifty-five gallons per minute is bled off from the circulating system. Just over two thirds of this is used for moistening sinter at the screening station to limit the emission of dust into the atmosphere. The remaining forty-five gallons per minute is withdrawn with the solids in the form of sludge and pumped into the sludge drying pond.

The bulk of the water from the sludge contained in the pond evaporates from the surface into the atmosphere. The remainder seeps through the sand-retaining embankment and joins the general plant drainage which is collected for use at the sinter plant and coke quenching stations. The dilution is such that any excess drainage pumped from the works is of a non-polluting character.

While the heavy bleed-off from the cooling system helps to limit the formation of scale deposits in the pipes, washers, cooling tower etc., resulting from the impurities such as calcium, zinc and lead which are picked up by the water during its contact with the gas, an economic method of eliminating the deposition has not yet been found. The use of acid to lower the pH value, organic dispersants, and inhibitors of various kinds have been tried with varying degrees of success. These chemicals are however costly when dealing with a water of this nature. Much effort is being put into the search for an economic answer to the problem.

<u>Section-mills water-circulating system</u>

The water used for cooling and washdown in the mills is contained in a recirculating system. Fig. 8 is a diagram of the equipment provided to permit recovery and re-use of the water. It can be seen that three types of water - dirty, hydro-cycloned and filtered - are used.

The water drawn from the scale pit by the dirty water pumps is split into two streams: one returns directly to the mill for scale washdown; the other is taken to a battery of hydraulic cyclones for removal of the bulk of the suspended solids. Twelve hydrocyclones with a diameter of twelve inches and a cone angle of twenty degrees are installed in three banks of four per bank, two banks being in use at any one time. Each unit is reducing the solids content of three hundred gallons per minute of water from approximately three hundred parts per million to an average of eighty-five parts per million. To ensure that the flow through the hycrocyclones remains close to the designed quantity in spite of variations in mill demands - an essential feature of optimum performance of the units is to be attained - the quantity delivered to the hydrocyclones is in excess of the normal mill requirements. Variations in demand by the mills are catered for by automatic variation of the excess water which is returned to the scale pit. The underflow from the cyclones which amounts to thirty-six gallons per minute, i.e. 1½% of the feed, and contains an average of fourteen thousand parts per million solids of particle size generally above forty microns, is allowed to settle in a sludge skip, the supernatant liquor being returned to the main scale pit.

The delivery from the hydrocycloned-water pumps is also divided, one part returning to the section mills for roll-barrel cooling, the other being filtered and cooled before being delivered to the roll bearings, guides, oil coolers etc. in the mills.

Sand pressure filters are used to reduce the solids content of the hydrocycloned water to approximately five parts per million and to remove oil and grease picked up by the water used in the mills. The filtering media are similar to that used at the water softening plant, illustrated in Fig. 3. Satisfactory filtration of the water is achieved at a flow rate of two gallons per minute per square foot of filter area, at which rate backwashing of the media is necessary at intervals of twenty-four hours. A filter is taken out of service, the media are agitated with air at a pressure of 7½ lb/in^2 and then washed with clean water in the direction opposite to the normal flow at a rate of seven gallons per minute per square foot of filter area until clean. The whole operation usually takes about fifteen minutes. The dirty backwash water is discharged into a tray-type clarifier which consists of a cylindrical tank divided by a tray into two superimposed settling compartments. Each compartment has its own set of slowly revolving rakes carried on a single vertical central drive-shaft. In this application the upper compartment mainly acts as a buffer storage tank by receiving a large flow of water in a short period and passing it through to the lower compartment at a much reduced rate over a longer period. The rate of flow through the lower compartment is controlled by the pumps which feed the clarified water back into the main circuit.

The millwater system as it now exists is a combination of that which was provided in 1948 to serve the section mills, with additions and modifications in 1961 to enhance its capacity to supply the universal beam mill. The two conical concrete sumps designed to permit transfer of the scale water from the universal beam mill stands into the scale pit which existed, without permitting scale to settle in them, and the hydro-cyclones, were part of those modifications. Both innovations have proved satisfactory.

Limitation of space was the major factor that led to the installation of hydrocyclones in preference to the type of clarifier used in two other rolling-mill water systems on the works. A battery of cyclones capable of handling one thousand gallons per minute can be accommodated in a space not more than ten feet long by three feet wide by ten feet high compared with a surface area requirement of not less than one thousand five hundred square feet for a clarifier handling a similar volume. Also the capital cost per thousand gallons per minute is much lower - not more than 15% of that for a clarifier. The main disadvantages of hydrocyclones are -

(1) Power consumption owing to the pressure drop through them: approximately twenty horse power is absorbed per thousand gallons per minute capacity compared with four horse power for a clarifier system.

(2) Further treatment of at least a portion of the water must be applied, since the cyclone is a classifier as distinct from a clarifier. One set cannot remove the full range of particles and the finer ones cannot coalesce because of the centrifugal action. Unless measures are taken to remove some of the fine particles from the overflow water, concentration occurs until a slurry of fines is eventually produced.

With a system such as that provided at the section mills the waste water discharged is only a nominal amount and is of such a quality that it does not constitute a pollution problem.

CONCLUSION

While it is generally accepted that a large quantity of water is essential to the operation of an iron and steel works, it is not always appreciated that only a small proportion of it is actually consumed in the process or contaminated to such a degree as to render it unsuitable for further use in the works. The extent to which re-use is carried out in a plant must however be examined in relation to the availability of assured sources of fresh water, facilities for discharge of effluents and the economics of the adoption of recycling systems or once-through operation.

Extensive recycling and re-use at Appleby-Frodingham was originally brought about by a localised shortage of water. Legislation during recent years to conserve national water resources and prevent pollution of rivers has however given added incentive since economy in the use of water and limitation of liquid effluent discharge go hand in hand.

When it is borne in mind that the annual cost of water services to the works is of the order of three quarters of a million pounds it will be realised that attention to efficient utilisation is well worth while.

ACKNOWLEDGMENT

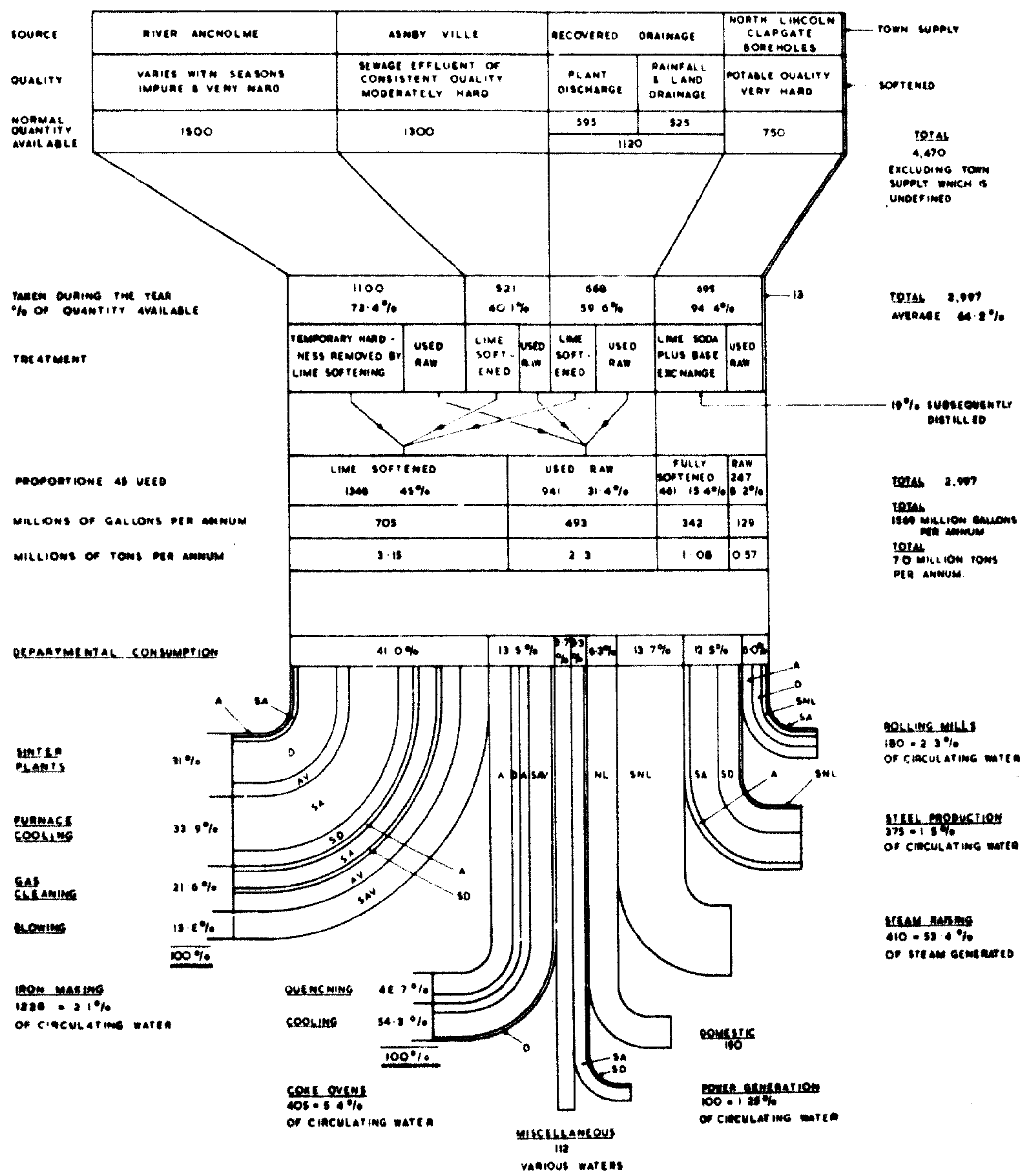
The author gratefully acknowledges the permission of the Appleby-Frodingham Steel Company to present this paper.

Figure 1

WATER SUPPLY & USAGE FOR THE YEAR ENDING MARCH 1967

APPLEBY FRODINGHAM STEEL CO SCUNTHORPE LINCS

BAND WIDTHS ARE PROPORTIONAL TO THE RATES OF FLOW
ALL QUANTITIES ARE IN GALLONS PER MINUTE UNLESS STATED OTHERWISE



WATER CONSUMED = 4·88 TONS PER TON OF STEEL
WATER CIRCULATED = 176 TONS PER TON OF STEEL
FRESH WATER INTAKE = 2329 gpm = 3·82 TONS PER TON OF STEEL

11% DISCHARGED AS EFFLUENT — 89% LOST AS VAPOUR

ABBREVIATION KEY

ANCHOLME	RAW	A
	SOFTENED	SA
ASHBY VILLE	RAW	AV
	SOFTENED	SAV
DRAINAGE	RAW	D
	SOFTENED	SD
NORTH LINCOLN	RAW	NL
	SOFTENED	SNL

Figure 2

FLOW DIAGRAM SHOWING RE-USE OF SEWAGE EFFLUENT AT THE IRONWORKS OF APPLEBY-FRODINGHAM STEEL CO. SCUNTHORPE

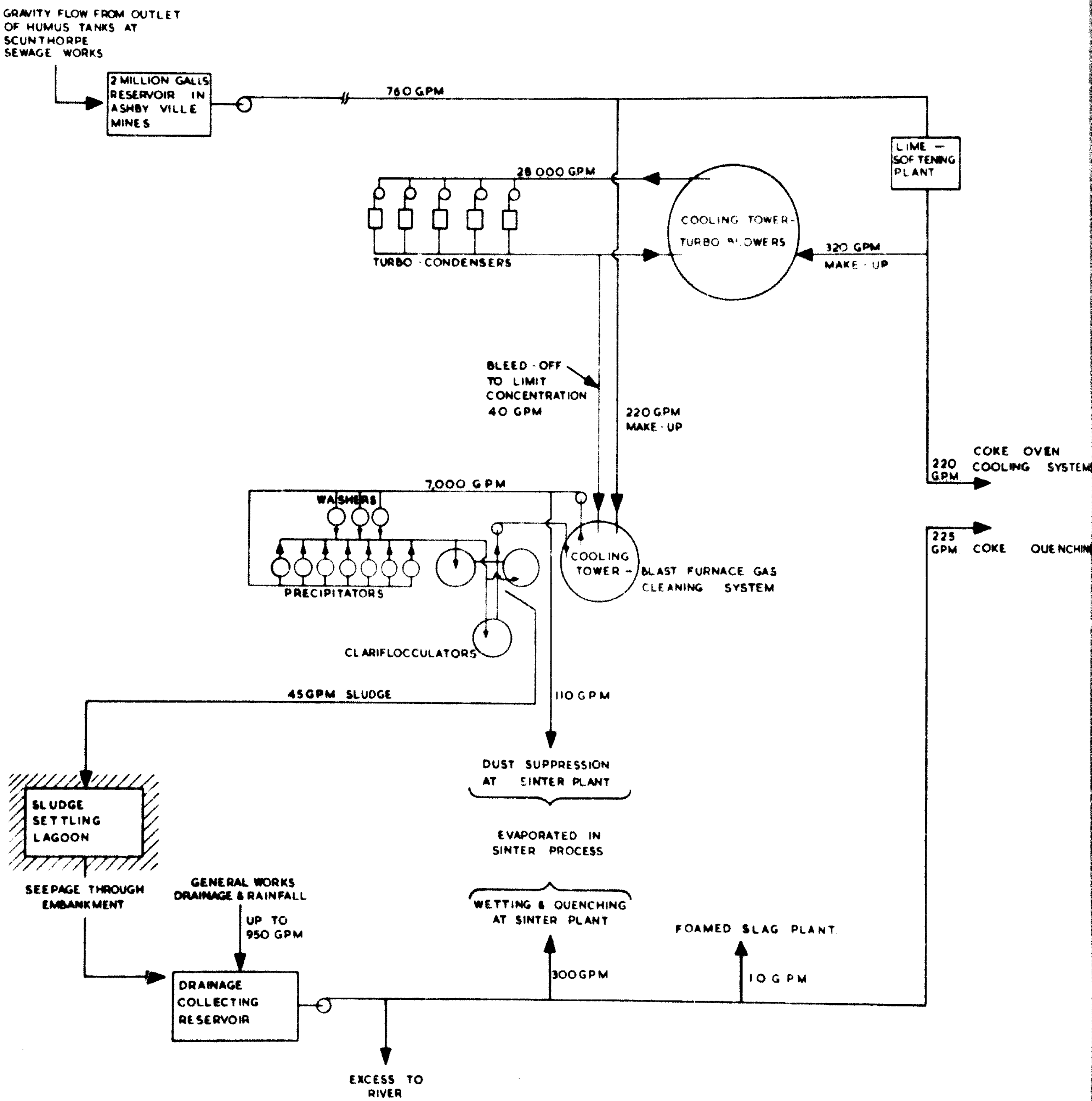
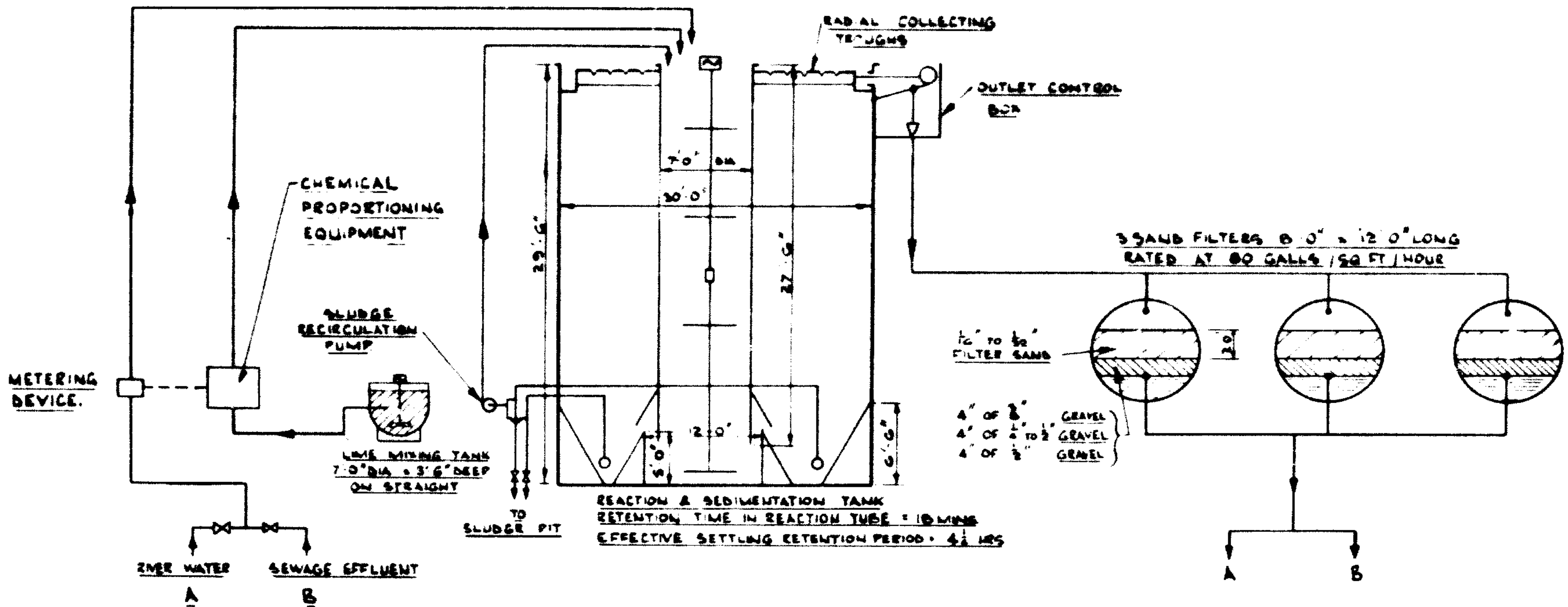


Figure 3

DIAGRAM SHOWING DIMENSIONS OF A 22000 GALLS/HR. LIME SOFTENER & TYPICAL RESULTS OBTAINED WHEN TREATING RIVER WATER OR SEWAGE EFFLUENT



		A	B
TOTAL HARDNESS	ppm	460	310
ALKALINE	-	180	160
NON-ALKALINE	-	280	150
CALCIUM	-	420	270
MAGNESIUM	-	40	40
SUSPENDED SOLIDS	-	14	15
PHOSPHATE AS PO_4	-	TRACE	14
pH VALUE		7.8	7.6

		A	B
TOTAL HARDNESS	ppm	316	230
ALKALINE	-	36	80 ($CaCO_3$ + $Ca(OH)_2$)
NON-ALKALINE	-	280	150
SUSPENDED SOLIDS	-	< 3	< 3
PHOSPHATE AS PO_4	-	NIL	0.3
pH VALUE		10.2	10.3

Figure 4

View of inside of cooling water pumphouse at the iron works

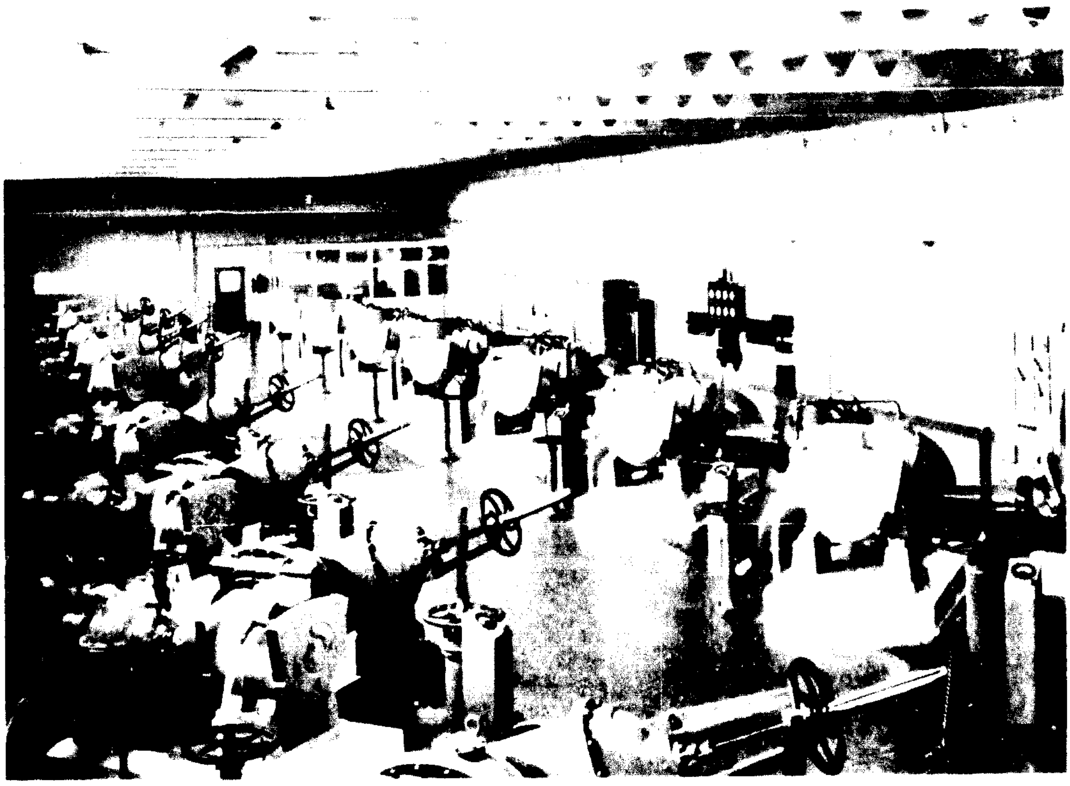


Figure 5

Natural draught tower cooling water for the turbo-blower condensers and two blast furnaces

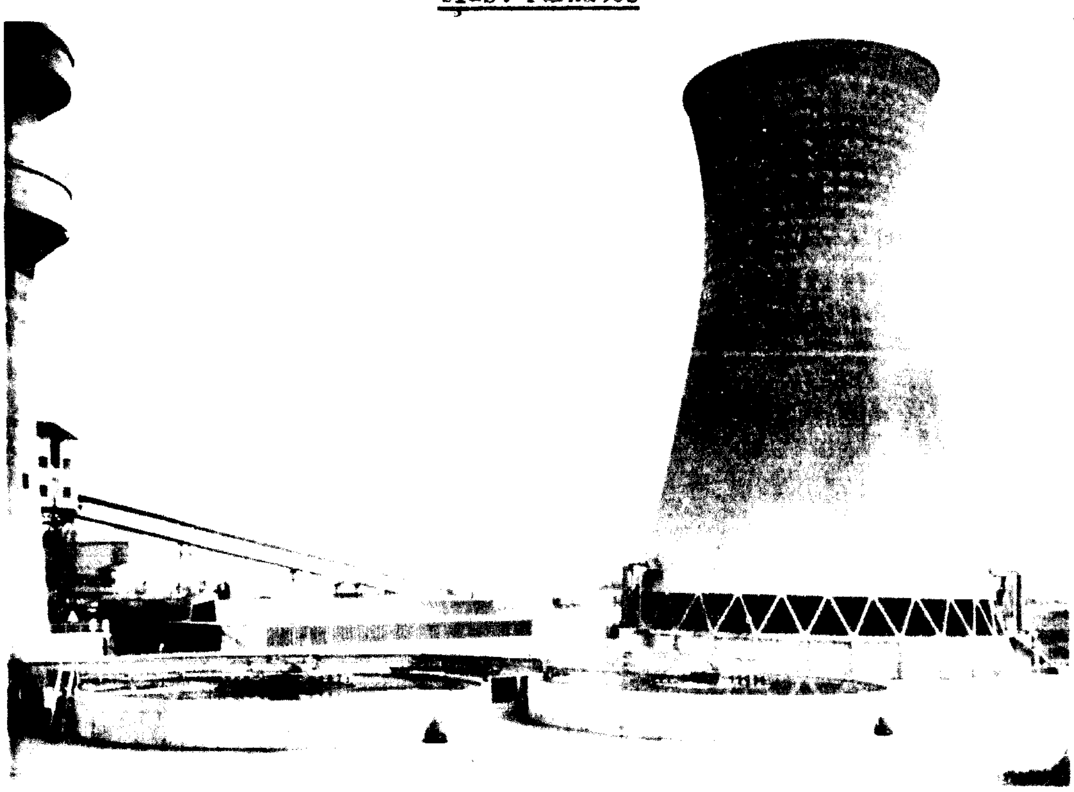


Figure 6

DIAGRAMMATIC ARRANGEMENT OF EVAPORATIVE COOLING SYSTEM ON A STEELMAKING FURNACE

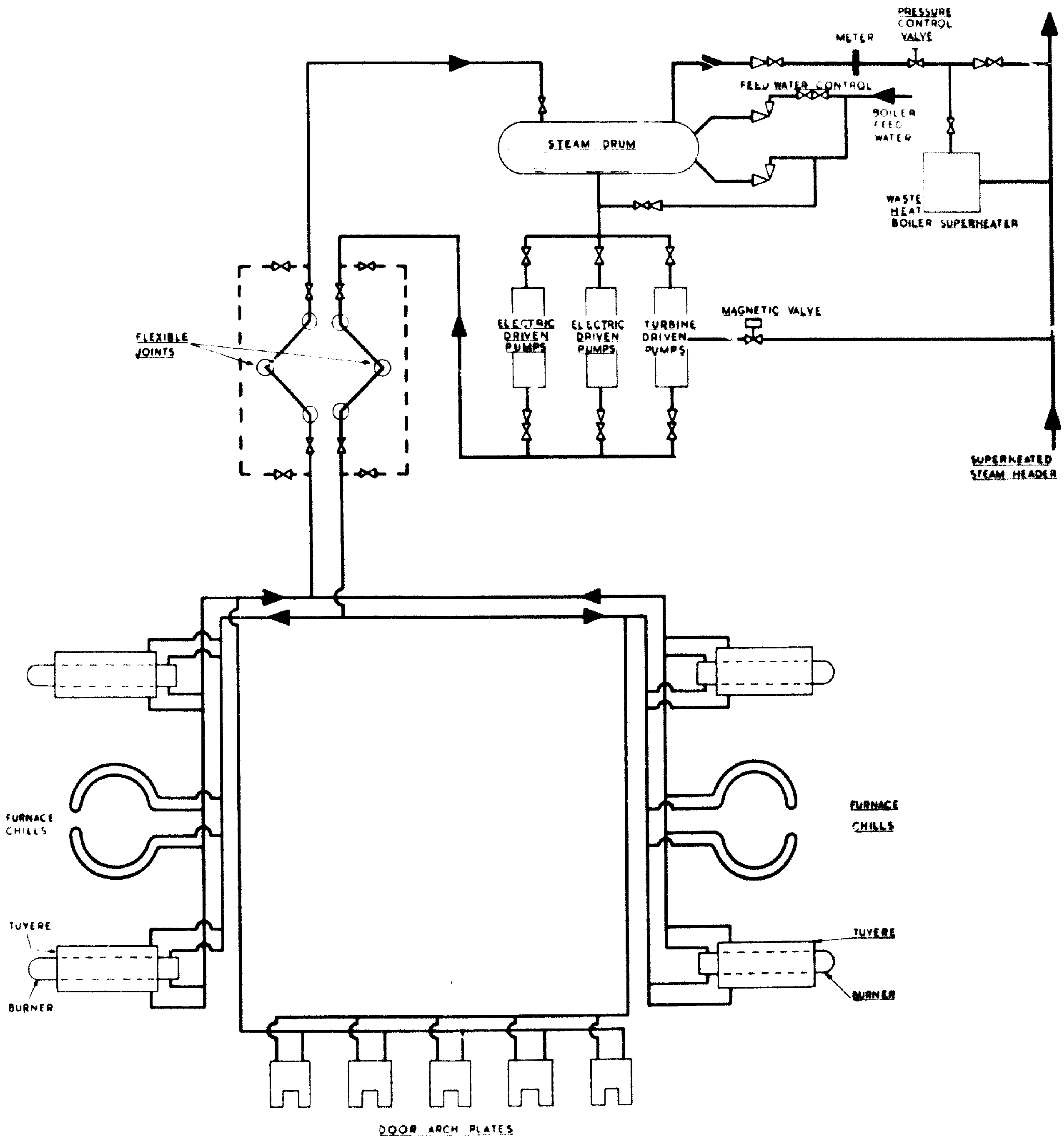
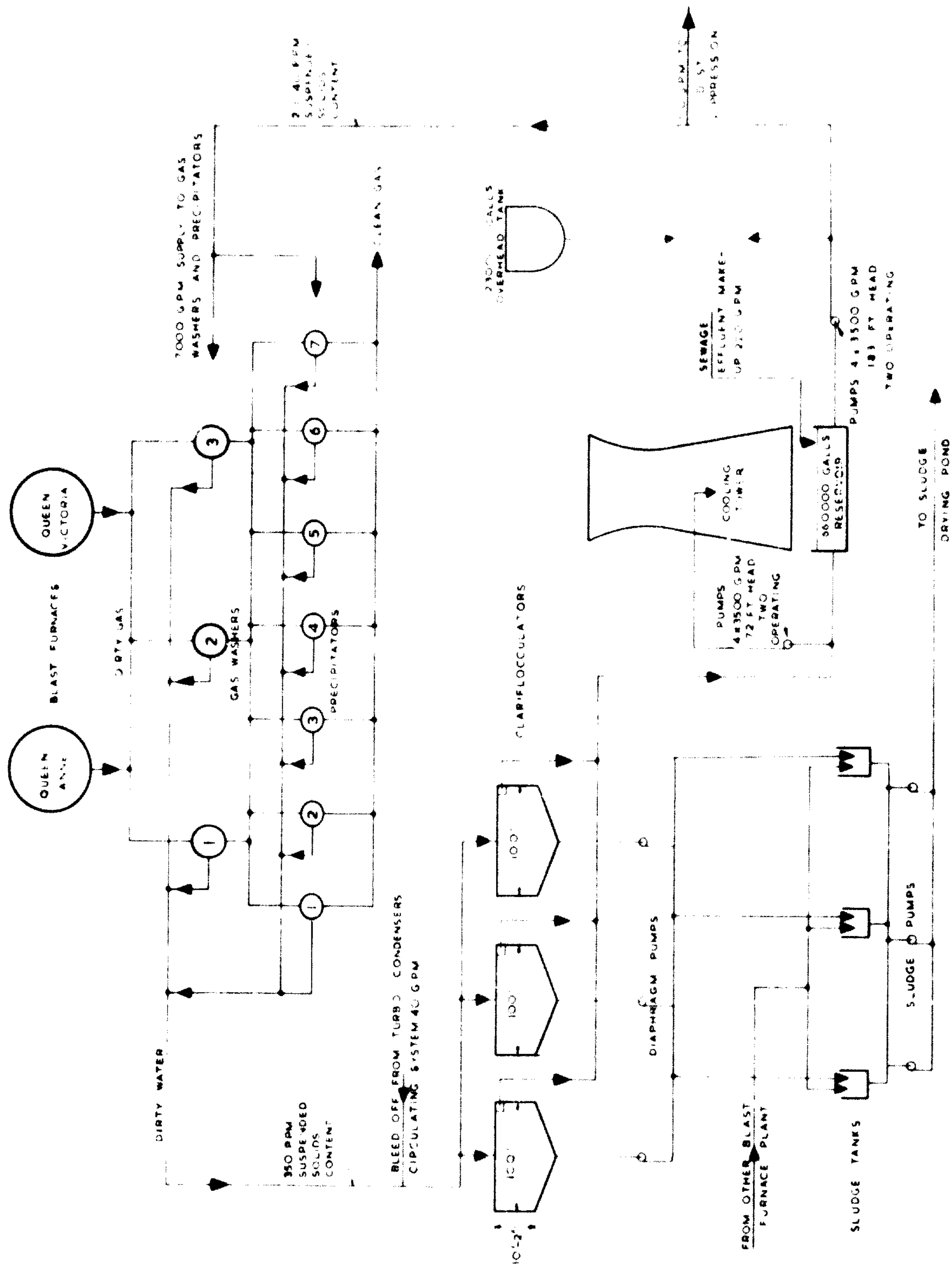
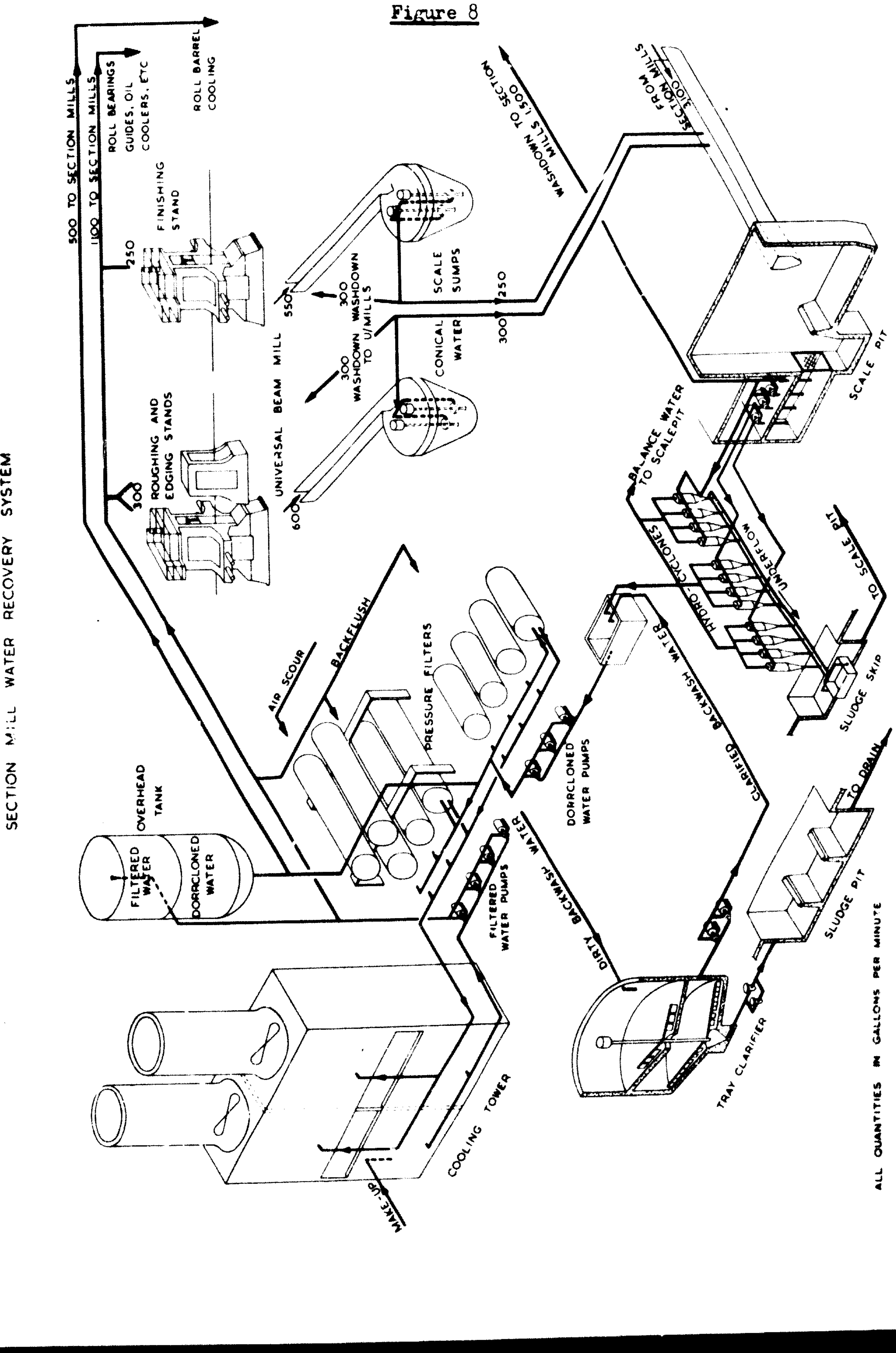


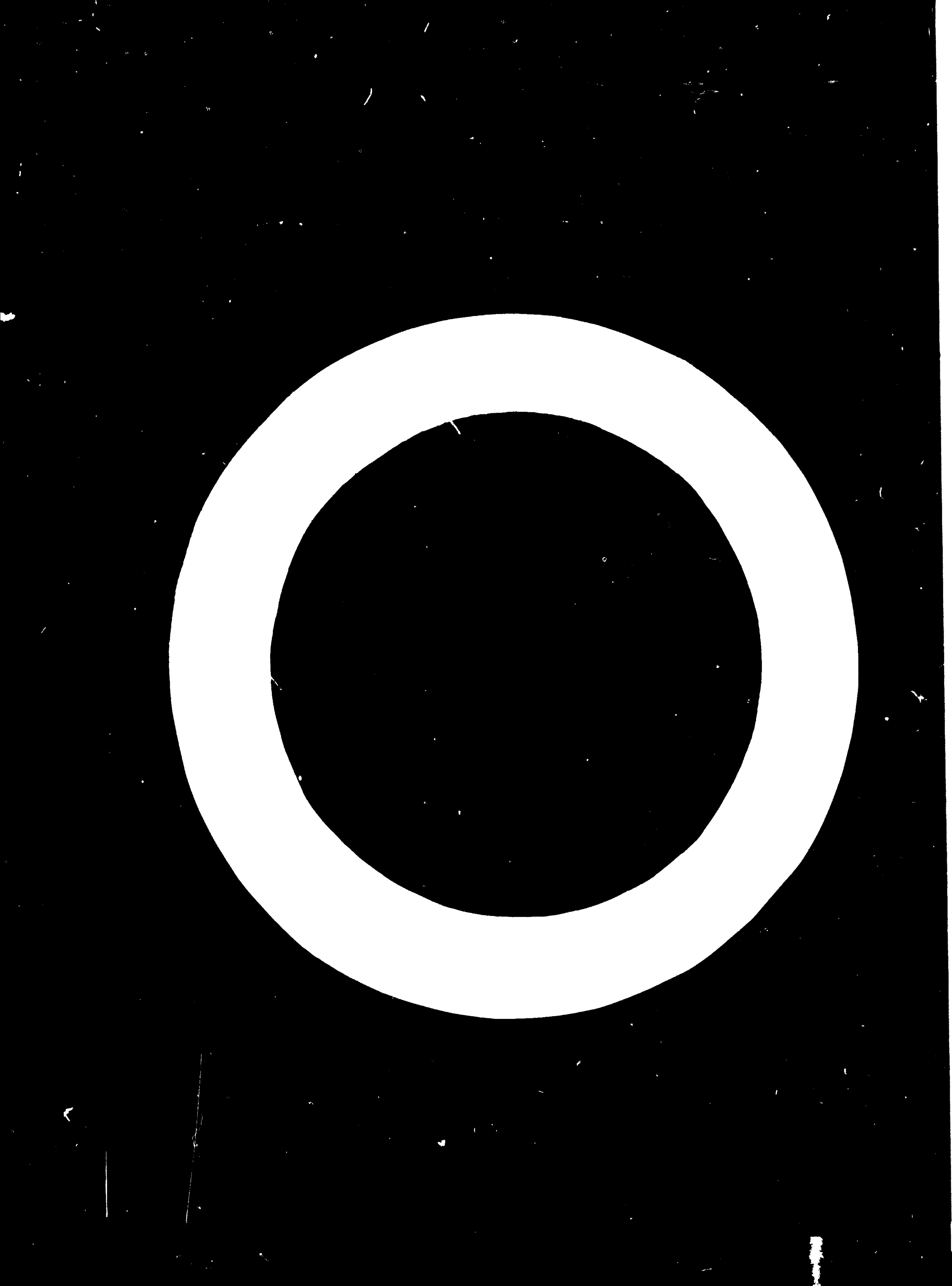
Figure 7



DIAGRAMMATIC ARRANGEMENT OF A BLAST FURNACE GAS CLEANING SYSTEM SHOWING WATER FLOWS

Figure 8


SECTION MILL WATER RECOVERY SYSTEM
500 TO SECTION MILLS
1100 TO SECTION MILLS
ROLL BEARINGS GUIDES, OIL COOLERS, ETC
ROLL BARREL COOLING
FINISHING STAND
ROUGHING AND EDGING STANDS
UNIVERSAL BEAM MILL
250
300
550
600
300 WASHDOWN
300 WASHDOWN TO U/MILLS
CONICAL WATER
SCALE SUMPS
WASHDOWN TO SECTION MILLS 1,500
FROM SECTION MILLS 3100
SCALE PIT
BALANCE WATER TO SCALEPIT
HYDRO-CYCLONES
UNDERFLOW
TO SCALE PIT
SLUDGE SKIP
BACKWASH WATER
CLARIFIED
TO DRAIN
SLUDGE PIT
TRAY CLARIFIER
DIRTY BACKWASH WATER
DORRCLONED WATER PUMPS
FILTERED WATER PUMPS
PRESSURE FILTERS
AIR SCOUR
BACKFLUSH
OVERHEAD TANK
FILTERED WATER
DORRCLONED WATER
COOLING TOWER
MAKE-UP
ALL QUANTITIES IN GALLONS PER MINUTE



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WATER SUPPLY, RE-USE AND DISPOSAL[1/] AT AN INTEGRATED IRON AND STEEL WORKS IN GREAT BRITAIN

by

G. W. Cook,
United Kingdom

SUMMARY

INTRODUCTION

While upwards of two hundred tons of water are used to produce one ton of steel in an integrated works the actual consumption is not more than about five tons per ton of steel, the bulk of it being lost as vapour into the atmosphere. As far as the water resources of a particular area are concerned this consumption may however be increased many times by the discharge of clean or lightly contaminated waters from a works direct to the sea, river estuaries or highly-polluted inland waters. The conservation of water and disposal of effluents should therefore be viewed as a common problem.

* This is a summary of a paper issued under the same title as ID/WG.14/11.

1/ The views and opinions expressed in this paper are those of the author and do not necessarily reflect the views of the secretariat of UNIDO. The document is presented as submitted by the author, without re-editing.

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Such a view is held at the Appleby-Frodingham works of the Midland Group of the British Steel Corporation. The works, which are situated at Scunthorpe in the county of Lincolnshire approximately eight miles south of the Humber and four miles east of the river Trent, have an annual steel production in excess of one and three-quarters of a million ingot tons.

Measures taken at those works to make full use of the available water and limit effluent discharge are described in the paper since it is thought that some of the problems met there and the methods adopted to overcome them may apply to other plants, particularly those where recirculation of water is a necessity.

SYNOPSIS

The first part of the paper describes the fresh-water services to the works including the sources of supply, their quality, distribution, treatment and utilisation. The remainder deals with the use of recycling systems for cooling only, and for combined cooling and cleansing purposes. In addition to details of pumps, cooling towers etc. employed, an economic comparison is given of the use of air/water heat exchangers and natural and mechanical-draught cooling towers for specific duties. The application of cooling systems designed to generate steam for plant use - referred to as evaporative cooling - is described.

Details of two examples of combined cooling and cleansing systems are given: One for a blast furnace gas-cleaning plant and the other for a hot-rolling mill producing sections and universal beams.

The extent to which re-use of water is applied at the works is such that the present intake of fresh water amounts to less than four tons per ton of steel produced.

FRESH WATER SERVICES AT APPLEBY-FRODINGHAM

Details of the supply and usage of water for the year ending March 1967 are shown in diagrammatic form as Fig. 1 (copy attached).

The Works draws its fresh water from three sources: a small river; the town sewage purification works; and boreholes sunk into the limestone strata. Water drawn from the river and the sewage works is used for cooling furnaces, quenching hot materials and general works purposes while that from the boreholes supplies the steam-raising, hygiene and amenity demands. Dual electric power supplies at the pumping stations, emergency reservoirs and ring-main distribution systems on the works help to ensure continuity in the water supplies.

The water from all three sources is very hard and just over 60% of it is softened before use. The alkaline hardness of the river supply and the sewage effluent is removed with lime in precipitation-type softeners before those waters are used to replace the losses from cooling recycling systems. The borehole water is chlorinated at source to safeguard the drinking supplies. The portion used for steam-raising is lime-soda softened, followed by base-exchange treatment to reduce the hardness to commercial zero.

The solids arising from the softening process are collected as a sludge which is used for liming the moulds at the pig-iron casting machine or discharged into a sludge-drying lagoon.

The sources of fresh water drawn upon by the works are capable of producing an assured supply at the rate of three thousand five hundred and fifty gallons per minute and the average demand made upon them amounts to about 70% of that figure. Nearly 90% of the water brought into the plant is eventually lost as vapour into the atmosphere; the remainder is discharged as effluent with some surface drainage and process liquids.

RECIRCULATING COOLING SYSTEMS

Since the quantities which can be extracted from the sources of supply are limited, recycling of water is adopted. Twenty-nine separate systems with a total flow of approximately one hundred and twenty thousand gallons per minute are in use on the works. They may be divided into two groups:

(1) indirect cooling systems in which the water is used only to remove heat from condensers, furnace elements, oil coolers etc.;

(2) direct cooling systems in which the water serves as both a cooling and a cleansing medium, e.g. in gas cleaning, rolling mill and continuous casting plants.

Certain items of equipment are common to both types of system. They include -

Pumps

There is a total of two hundred and ninety electrically-driven centrifugal pumps with capacities ranging from fifty to six thousand gallons per minute to circulate water round the various systems. An average of one hundred and sixty is in use at any one time, the remainder being provided as stand-by units or for use in an emergency, e.g. storms. Practically all units are designed to operate at 75 to 80% efficiency when handling their rated volume and at this level of operation the total horsepower absorbed is just over ten thousand. The majority have bronze impellers and cast-iron casings which have normal lives of approximately ten years and twenty years respectively when handling fairly clean water.

Reservoirs

Each cooling system includes its own reservoir with a capacity at least equal to the water contents of the circulating system, together with sufficient margin to cater for normal water losses by evaporation etc. for a period of at least four hours should no make-up water be available. As far as is possible, sunlight is excluded from the reservoirs. This has proved effective in discouraging organic growths in the circulating water.

Balance and emergency supply tanks

Overhead tanks ranging in capacity from 15 thousand to two hundred and fifty thousand gallons, dependent upon the volume of water circulating in a system, are installed at heights of between forty and one hundred and seventy-five feet above site level to provide balance for the system and approximately twenty-five minutes reserve in case of temporary failure of electric power to the pumps.

High capital cost, limited reserve time, risk of flooding the pland during a major power failure and the long time taken to refill the tanks when power is restored are the major disadvantages of such a system. A combination of small overhead tanks to act as "balance" for the systems and diesel-driven stand-by pumps automatically brought into service when a reduction in water supply occurs is considered to be a better proposition than the provision of large reserves in high-level tanks.

Cooling towers

A total of twenty-six atmospheric cooling towers with heat-removal capacities ranging from about one hundred to three thousand seven hundred therms per hour are installed, the majority of them cooling water from around 95°F to 75°F. Nine are natural-draught chimney towers and seventeen are mechanical-draught towers.

While the capital costs of the latter are appreciably lower than those of an equivalent-duty natural-draught tower, the operating costs are higher. With a fairly light cooling duty, e.g. from 100°F to 90°F at an atmospheric wet-bulb temperature of 60°F, the total costs of both types for cooling a quantity of four thousand gallons per minute are similar if capital depreciation is allowed at 10% per annum. As the quantity decreases below four thousand gallons per minute the balance is increasingly in favour of mechanical-draught whereas increases in quantity above four thousand gallons per minute increasingly favour the adoption of natural-draught towers.

An air/water heat exchanger is installed in the cooling circuit at the continuous casting plant. A comparison of the capital and operating costs indicates that if the cost of fresh water exceeds about three shillings per thousand gallons, the savings in water justify the use of air/water heat exchangers where recooled water temperatures above about 125°F are permissible.

The total heat removed by the cooling towers on the works is of the order of eight thousand two hundred and fifty therms per hour which is equivalent to the heat content of approximately seven hundred thousand pounds of steam at a pressure of 200 lb/in^2. The incentives for reducing this wastage of heat are therefore by no means small.

If the cooling water is recycled under pressure without dissipation of its heat by a cooling tower or heat exchanger, some of it will be converted into steam which can be separated from the water and used for plant heating. This method, known as evaporative cooling, is applied to three steelmaking furnaces and one bloom reheater on the works where cooling at relatively high temperatures and pressures is permissible. Although it is initially more expensive than conventional water cooling, in addition to steam credits amounting to at least three thousand pounds (lb) per hour per furnace, evaporative cooling makes a significant contribution towards economy in the use of water on the works.

Direct Cooling Systems

In these systems the water, in addition to absorbing heat, frequently acts as a carrier of solids originating in the process. There are seven such major systems on the works serving gas-cleaning plants, rolling mills, pig-iron casting machines and plant for continuous casting of steel blooms. The equipment used to remove the solids from the water before it is recycled includes clarifiers, hydraulic cyclones and filters.

Two systems are described in the paper: one for a blast-furnace gas-cleaning plant and the other for the section-rolling mills.

Water system for blast-furnace gas cleaning

About twenty-eight gallons of water is used for each thousand cubic feet of gas cleaned in washers and electrostatic precipitators. The water suffers a rise in temperature of about 10°F and an increase in both suspended and dissolved solids content during its passage through the gas cleaning equipment. The suspended solids content of the water is reduced to twenty-five to forty parts per million in three hundred-foot diameter clariflocculators before being recycled. The precipitated solids are withdrawn as a sludge with not more than 10% solids by weight and pumped to a sludge-drying pond.

The impurities dissolved by the water in the gas-cleaning process include calcium, zinc, cyanides and lead which cause deposits in the pumps, cooling towers etc. and create a toxic effluent unsuitable for discharge to a clean river. An economic answer to the scale-deposit problem is still being sought. The use of some of the bleed-off from the system for quenching and dust suppression, and natural evaporation of the remainder from the surface of the sludge-drying pond, ensures that practically none of this water is discharged from the works.

Section-mills water-recirculating system

Hydraulic cyclones and sand filters are the main equipment employed to remove the scale, oil and grease before the water is re-used in the mills. The cyclones reduce the suspended matter in the water from approximately three hundred to eighty-five parts per million and the filters further reduce that figure to about five parts per million in addition to removing the oil and grease. The water used for backwashing the filters is fed into a tray-type clarifier for removal of the solids, oil and grease, before being returned to the mill circulating system.

The main advantages of hydraulic cyclones compared with clarifiers for removal of solids from mill water are that they occupy a much smaller area and involve less capital expenditure - not more than 5% and 15% respectively. Their main disadvantages are increased power consumption and the need for subsequent treatment of at least a portion of the water to prevent concentration of the finer solid particles in the recycled water.

CONCLUSION

The majority of iron and steel-making processes do not demand water of such a high purity as many industries, e.g. food, textiles and chemicals. Certain impurities in the fresh supplies and the water used in the plant can be tolerated. The extent to which water re-use is carried out in a works must however be examined in relation to the availability of assured sources of fresh water, facilities for discharge of effluents and the economics of the adoption of recycling systems or once-through operation.

Extensive recycling and re-use of water at Appleby-Frodingham was originally brought about by a localized shortage of water. Legislation during recent years to conserve national water resources and prevent pollution of rivers has however given added incentive. When it is borne in mind that the annual cost of water services to the works is of the order of three-quarters of a million pounds, it will be realised that attention to efficient utilisation is well worth while.

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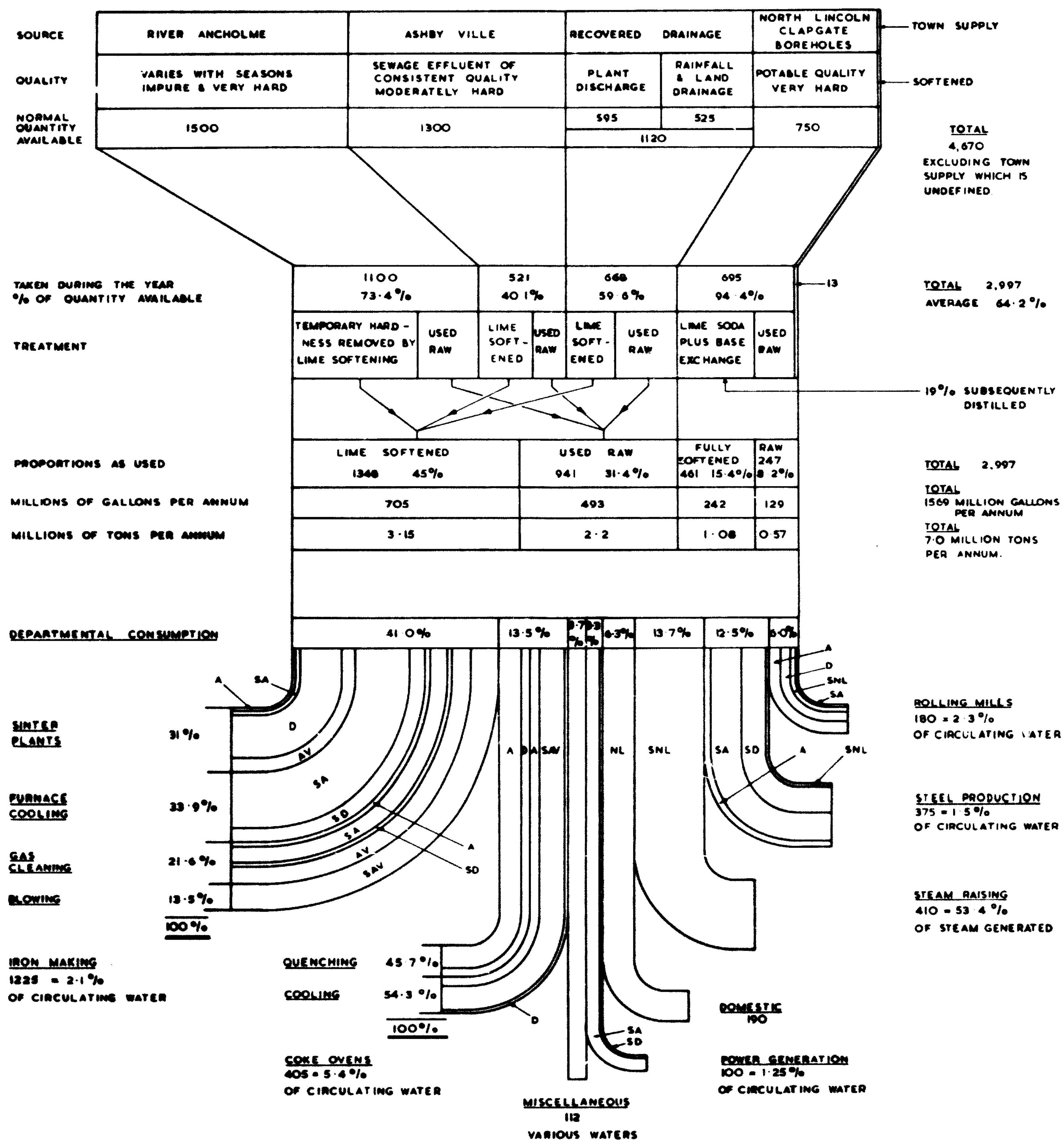

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FIG. 1

1. 4. 74