

GUNCOTTON AND ITS MANUFACTURE.

AN ACCOUNT OF MODERN METHODS.

BY COL. SIR FREDERIC L. NATHAN, R.A.

Concluded from Supplement No. 1749, page 19.

DIRECT DIPPING.

The first attempt attended with any success to overcome some of the disadvantages of the Abel process was the introduction of what is known as the direct dipping process. This system was used on a large scale at Nobel's factory at Ardeer, in Scotland, and I am indebted to the kindness of Mr. Lundholm for a description of it, of which the following is an abstract:

The installation consists of parallel double rows of long iron tanks known as "coolers." Iron pots termed "dippers," in which nitration is carried out, stand in the coolers, 62 to each cooler. Sliding wooden covers rest on the coolers to guide the fumes from the dippers into earthenware pipes with openings at intervals, through which they are drawn by exhaust fans. The mixed acid, either cooled or warmed as necessary, is carried by lead pipes placed between each row of coolers, and is supplied to the dippers through earthenware cocks at intervals.

Nitration.—The water in the coolers is kept at 15 deg. C. The dippers having been placed in position in the coolers, are each filled with 127 pounds of mixed acid by measurement, from the acid taps, $4\frac{1}{2}$ pounds of cotton waste are steeped in each dipper. To minimize decompositions each charge of cotton waste is added in about ten instalments. The wooden covers are only removed to allow steeping to be done, and are then at once replaced. The temperatures of nitration are: Initial temperature of mixed acid, 15 deg. C.; maximum after steeping, 25 deg. C.; temperature at end of nitration, 20 deg. C. The duration of the nitration varies according to the output required from the plant. One, two or three shifts may be worked per 24 hours, and the time of nitration may therefore be 24, 12, or 8 hours respectively.

The average composition of the mixed acid for a 12 hours' immersion is as follows: Sulphuric acid, 75.0 per cent; nitric acid, 15.75 per cent; nitrous acid, 1.30 per cent; water, 7.95 per cent. For an eight hours' immersion a higher percentage of nitric acid and less water is used; for a 24 hours' immersion less nitric and more water. The average composition of the waste acid for a 12 hours' immersion is: Sulphuric acid, 77.8 per cent; nitric acid, 11.0 per cent; nitrous acid, 1.5 per cent; water, 9.7 per cent.

Recovering the waste acid.—When the nitration is complete, the "dippers," covered with light aluminium lids, are placed on barrows, wheeled to the centrifugals, situated at the end of the "coolers," and the whole contents tilted out into the centrifugal. Four dippers are loaded into each centrifugal, and the guncotton having been uniformly spread round the basket, the centrifugal is run for six minutes, to remove waste acid. At the end of that time about 1 pound of waste acid is still adhering to each pound of guncotton. The centrifugal cover, made of light aluminium, is not fixed to the centrifugal in any way, so that as little resistance as possible may be offered when there is a decomposition. This is the usual arrangement in the case of acid centrifugals. The cone of the centrifugal projects through a circular opening in the center of the lid and is covered by a small loose aluminium box. Small holes are cut in the sides of this box, and are of service in warning the workmen when there is a decomposition, as fumes are generally seen to issue there first.

Drowning the guncotton.—When the waste acid has been removed, the guncotton is quickly lifted out of the centrifugals and thrown under the revolving paddles of the drowning tanks, which immediately immerse it. The men who do the discharging are provided with rubber gloves and wear thick flannel hoods, which completely cover the head, arms, and breast. The hoods are fitted with strong glass windows, and are connected by light rubber tubing to a supply of pure compressed air.

Prewashing.—After a given quantity of guncotton has been drowned, the water in the tanks is run off and the guncotton thrown on to draining tables forming part of the drowning tank. It is then loaded into the prewashing centrifugals, the acid water wrung out, and washed for a few minutes with cold water from a hose, to remove adhering acid. No special precautions, however, are taken to remove all acid at this stage. The bulk of the water having been removed, the guncotton is loaded from the centrifugals into bogies, and conveyed to the boiling house.

* Read before the Society of Chemical Industry.

The 62 dippers in each cooler form a "charge." Eight charges are worked by each shift. The yield is 159 per cent of dry guncotton on the dry carded cotton. The output per shift consisting of 17 men is, therefore: $4.5 \times 159 \times 62 \times 8 \div 100 = 3,549$ pounds.

NITRATING CENTRIFUGALS.

The next attempt at simplifying the Abel process was one in which the nitration was effected in the acid centrifugal. A number of nitrating centrifugals have been patented, particularly in Germany, but the best known patterns are those of Messrs. Selwig and Lange, of Brunswick.

The latest pattern is known as the "nitrating centrifugal with acid circulation." It consists of the usual outer casing with cover, and an under-driven rotating basket perforated with a number of holes. The machine is provided with a hinged cover with communication to an exhaust fan, and there are pipes with cocks suitably arranged for running in the nitrating acid and drawing off the waste acid. The method of working is briefly as follows: The basket is rotated slowly, and the nitrating acid run into it and between it and the iron casing, up to about the rim. The cotton waste is introduced in small quantities at a time, and this may be done while the nitrating acid is running in. During nitration the basket is rotated at the rate of 20 to 30 revolutions a minute. The effect of this rotation is to cause the nitrating acid to circulate continuously through the cotton waste. On completion of the nitration the bulk of the waste acid is drawn off and the centrifugal set into rapid motion to get rid of as much more of the waste acid as possible.

According to Selwig and Lange's circular their centrifugals are now made in two sizes. The larger size nitrates 22 to $26\frac{1}{2}$ pounds of cotton waste, the smaller $14\frac{1}{2}$ to $17\frac{1}{2}$ pounds, respectively. The yield is stated to be 160 per cent. The time of a complete nitrating operation is an hour.

Messrs. Curtis and Harvey have an installation of these centrifugals at their Dartford Works; they are of the earlier or "without acid circulation" type, and of the smaller size. Mr. MacDonald has kindly supplied me with some details in connection with their working.

The charge is $17\frac{1}{2}$ pounds of cotton waste, the proportion of nitrating acid to cotton waste is 50 to 1, and its average percentage composition: nitric acid, 23.15; sulphuric acid, 69.35; water, 7.5. The nitrating operation for the production of cordite guncotton, from the running in of the nitrating acid to the removal of the guncotton, takes about an hour. The initial temperature is 15 deg. C., the final 23 deg. C. After extraction of the waste acid, the guncotton retains approximately its own weight of waste acid containing a fairly high percentage of nitric acid, which is lost in the immersing. Analyses of the waste acid made at Dartford show the following mean alteration in the composition of the nitrating acid, viz., a loss of 1.70 in nitric acid, and gain of 0.91 in sulphuric, and 0.76 in water.

DISPLACEMENT PROCESS.

Guncotton has been made at Waltham Abbey by the displacement process since August, 1905. The installation consists of a number of units of four pans worked together. The pans are of earthenware and circular,

are again connected to the nitrating acid supply pipe, to the strong and weak waste acid pipes, and to a waste water pipe, through a gage-box, where the rate of flow is determined while the waste acids are being run off. Gravities of the acids are also taken in this box. The process proceeds as follows:

A small perforated plate is placed over the outlet of each pan, and four perforated segment plates making a complete disk about one inch less than the inside diameter of the pan, are placed on the bottom. Aluminium fume hoods, which are connected to an exhaust fan, having been placed on the four pans, the stone-ware cock on the acid supply pipe is opened, and the acid allowed to rise in the pans to the proper level. The nitrating acid is cooled in summer and warmed in winter, so as to maintain the same temperature of final nitration all the year round. The composition of the nitrating acid is 70% per cent sulphuric acid, 21 per cent nitric acid, 0.6 per cent nitrous acid, and 7.9 per cent water; the quantity in each pan above the bottom plates is 600 pounds; and below the plates is an additional 50 pounds. A charge of 20 pounds of cotton waste is then immersed in the acid, handful by handful, aluminium dipping-forks being used for the purpose. When all the cotton waste has been pushed under the surface of the acid, perforated plates in segments are placed on the top of it, care being taken that all cotton waste is below the surface of the acid, and a film of water at a temperature from 5 deg. to 8 deg. C. is run very gradually on the surface of the plates through a distributor. The film of water prevents the escape of acid fumes and the fume hoods are then removed. The time required for dipping a charge is a quarter of an hour.

The nitration is allowed to proceed for $2\frac{1}{2}$ hours. At the expiration of this period the cock leading to the gage-box is opened, and the waste acid allowed to run off at the rate of about 17 pounds a minute. Water, cooled, if necessary, is run on the top of the perforated plates, through the distributor, at an equivalent rate. The major portion, amounting to about 80 per cent of the total waste acid, is returned to the acid store tanks to be revived with Nordhausen sulphuric and new nitric acids. The composition of this waste acid is 72.70 per cent sulphuric acid, 17.30 per cent nitric acid, 0.65 per cent nitrous acid, and 9.35 per cent water. The remaining 20 per cent of the waste acid is sent to the acid concentration factory for denitration and concentration. The quantity of acid thus dealt with amounts to about 4 pounds for every pound of guncotton. Its composition is 61.0 per cent sulphuric acid, 17.35 per cent nitric acid, 0.55 per cent nitrous acid, and 21.10 per cent water. A small proportion of the water which follows the recoverable waste acid is slightly acid to the extent of 0.1 pound for every pound of guncotton made. This is the total quantity of acid that is lost during the process. In the direct dipping and nitrating centrifugal processes the quantity of waste acid left in the guncotton is at least equal to the weight of the guncotton.

The whole of the acid is displaced in three hours, and the water, which should fill the pan, is run through the guncotton, the guncotton drained down and sent over to be boiled. These operations occupy about an hour.

The following table gives the principal figures in connection with the four nitration processes described:

Process.	Nature of Dipping Vessel.	Acids.					Cotton Waste Used, Pounds.	Acid Used per Pound of Cotton Waste, Pounds.	Time of Nitration, Hours.	Yield on Dry Cotton Waste, Per Cent.	Output per Man, per Week, Pounds.
		Analysis, Per Cent.				Quantity, Pounds.					
		Sulphuric Acid.	Nitric Acid.	Nitrous Acid.	Water.						
Abel	Cast-iron pan and earthenware pot.	74.00	18.00	0.60	7.40	13.75	1¼	11.0	12	163.75	458
Ardeer:											
Direct dipping.	Cast-iron pot	75.00	15.75	1.30	7.95	127	4½	28.2	12	159.10	1112
Dartford:											
Nitrating Centrifugal	Centrifugal machine	69.35	23.15	7.50	500—1100	16—24	50.0	1	160.00
Waltham Abbey:											
Displacement	Earthenware pan	70.50	21.00	0.60	7.90	650	20	32.5	2¼	170	1742

3 feet 6 inches in diameter, and 10 inches deep at the side of the pan; the bottom has a fall of 2 inches to the outlet, which is three-quarters of an inch in diameter; they are supported on earthenware pedestals about 1 foot 10 inches above the floor level. The four pans are connected together by lead pipes, and these

The following are the principal advantages which the displacement process possesses over the Abel process, and over the direct dipping and nitrating centrifugal processes where they are similar to the Abel process.

1. The displacement process takes the place of the

processes of dipping, squeezing out excess acid, digesting in pots, acid centrifuging, immersing, and water centrifuging.

2. The actual dipping of the cotton waste is a very much less laborious operation—the heavy labor of squeezing out the excess acid is done away with, the absence of fumes makes the work much healthier, and injuries to workmen from acid splashes are almost unknown.

3. Loss of guncotton due to decomposition in the digesting pots and acid centrifugals, and consequent inconvenience and danger to workmen from nitrous fumes, are done away with, and the heavy loss from breakages of pots and lids is saved. Three and a half years' experience has proved that the earthenware pans are very lasting.

4. Fumes during dipping, loading, and unloading acid centrifugals and immersing, are avoided.

5. The quantity of acid lost is very much reduced. This reduction means also very much less pollution of the escaping washing water.

6. The recovered waste acid is very much cleaner, a matter of the greatest importance from the point of view of revivification and concentration.

7. The mechanical loss of guncotton in the acid and water centrifuging processes, and in the immersing process, is saved.

8. A more thorough preliminary washing of the guncotton is obtained with an expenditure of about one-fifth of the quantity of the water, and less boiling, with consequent consumption of steam, is required in order to reach a given standard of purity.

9. Great saving in power is gained by the abolition of the acid and water centrifugals, and in the reduction in the quantity of water which has to be pumped.

10. Renewals of plant, and repairs to plant and buildings are exceedingly low.

11. The number of hands employed for any given output is much less—the total cost of labor being reduced by two-thirds.

12. The yield is improved; it averages 170 per cent.

13. Finally, a more stable guncotton, of more uniform composition, is produced. It is also far cleaner, and contains notably less mineral matter.

STABILIZATION.

Boiling.—Originally stabilization was effected by prolonged washing in cold running water followed by a very short treatment with a boiling alkaline solution. Boiling, as now understood, did not form part of the process of guncotton manufacture when manufacture was started at Waltham Abbey early in 1872. About the middle of 1873, however, boiling vats were put up at Waltham Abbey, but no records exist, unfortunately, about the details of the early boiling processes. In the official "Notes on Gunpowder and Guncotton," published by the War Office in 1878, it is stated that guncotton manufactured at Waltham Abbey underwent two boilings by steam in wooden vats for 8 hours each, the water being extracted after each boiling by wringing for 3 minutes in clean water centrifugal machines. The same boiling process was in use in 1888, according to a later edition of the same book. Five years later each boiling was extended to 12 hours, and the boiling lasted for 5 days and nights—that is, the guncotton received 10 boilings of 12 hours each. In April, 1894, this system of boiling was replaced by a system characterized by short boilings at the commencement of the process, the time of successive boilings being gradually increased. The scheme of boiling was as follows:

No. of Boiling.	Duration in Hours.	No. of Boiling.	Duration in Hours.
1	2	7	6
2	2	8	6
3	4	9	9
4	4	10	9
5	6	11	12
6	6	12	12

This system of boiling was continued with but slight modifications until August, 1905. On the introduction of the displacement dipping process it was found, as already stated, that guncotton made in this way was brought to a condition of stability by the boiling process then in use, and just referred to, at an earlier stage than guncotton made by the Abel process. A probable explanation of this fact is that during the displacement process a zone of acid liquid at a comparatively high temperature—somewhere about 40 deg. C.—passes through the whole of the guncotton in the dipping pan. The action of this hot acid liquid may be to oxidize certain organic impurities which are certainly present, and to cause the breaking down of unstable nitrogen compounds into soluble or non-reactive bodies. Systematic experiments were therefore carried out in 1905, to determine the most suitable and most economical method of purification by boiling, for displacement process guncotton. In the principal experiments two types of boiling were employed—one in which long boilings were used at first, followed by short boilings; the

other in which short boilings were used at first, followed by long boilings. The following deductions were made from the results obtained in these experiments:

1. Purification of guncotton obtained by means of long boilings at the beginning followed by shorter boilings later, is superior to that obtained when the reverse condition holds. This is substantiated by the following considerations: Examination of the waters showed that neutrality is obtained earlier; that less decomposition of the guncotton takes place; that the stability, as shown by the various stability tests, is greater; and that a stable condition is attained earlier.

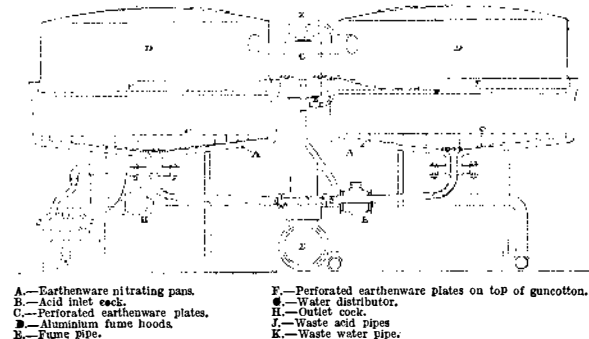
2. A displacement washing after a long acid boiling at an early stage is a beneficial treatment. This treatment is probably responsible for the early attainment of neutrality.

The system of boiling determined on as a result of these experiments was as follows:

No. of Boiling.	Duration in Hours.	No. of Boiling.	Duration in Hours.
1	12	6	4
2	12	7	4
3	4	8	2
4	4	9	2
5	4	10	2

With a cold water displacement wash after the first two boilings. A full account of these investigations was given in a paper on the purification and stabilization of guncotton, read by Dr. Robertson before this Section on June 16th, 1906. This system of boiling is still in use at the Royal Gunpowder Factory.

The question of how the purification of guncotton can best be effected cannot, however, be considered as settled, nor can the system which has just been described, although it undoubtedly gives an excellent guncotton at the Royal Gunpowder Factory, be applied to guncotton made by other processes, at other factories, without full investigations as to its suitability. Another matter which must be taken into account in connection with the purification of guncotton by boiling, is the nature of the water available. The water at Waltham Abbey is very hard, and its alkalinity may



WALTHAM ABBEY GUNCOTTON DISPLACEMENT PLANT.

be an important factor in the success of the boiling treatment in use there. This question is perhaps connected with another one, and that is, that the boiling of guncotton can be carried too far. The effect of boiling, while it no doubt breaks down impurities, also no doubt breaks down the stable ester itself. It is well known that if guncotton is boiled for a sufficiently prolonged period, the percentage of soluble matter will rise and the nitrogen-content will fall. The breaking down of the ester will be accompanied by the formation of acid bodies, and the presence of alkali in the water will neutralize them and prevent them from reacting on the guncotton.

I have been obliged, owing to want of time, to treat this question of purification very briefly, but it is undoubtedly the most important one in connection with the manufacture of guncotton. One or two matters have been touched upon, in connection with which further work is necessary, but there are many others which will repay very careful investigation and research.

PULPING.

On completion of the boiling process the guncotton is transferred to a beating engine somewhat similar to that employed for pulping the raw material used in the manufacture of paper. It consists essentially of a large iron roller armed with steel knives, and a bed-plate also provided with knives. The roller revolves, and as the guncotton passes between the two sets of knives, it is reduced to pulp of any desired fineness. As the pulping process proceeds, the roller is gradually lowered nearer to the bed-plate.

Since the introduction of a thorough system of purification by boiling, Abel's original idea that the pulping and washing the guncotton received in the pulping process had a very material effect on its purification, no longer holds good to the same extent. At the same time there is no doubt that the very long staple guncotton before pulping retains in its tubes unstable bodies which no reasonable amount of boiling will remove. The effect of pulping is to materially re-

duce the length of the fibers and, at the same time, to produce a certain amount of crushing in them. This allows of impurities of an acid character in the tubes being removed, either mechanically or by diffusion.

REMOVAL OF FOREIGN BODIES.

After pulping, it is now customary to treat the guncotton in some mechanical way, in order to remove from it particles of metal, grit, and foreign bodies of a similar character. At the Royal Gunpowder Factory this is effected by running the guncotton pulp, suspended in a large volume of water, through grit traps, placed at intervals in a long shallow trough, the bottom of which is covered with a blanket. The foreign bodies, being almost entirely heavier than the guncotton pulp, are retained in the grit traps, and the fine sand, also present in some quantity, is caught by the woolly blanket. An electromagnet in the last grit trap removes any magnetic particles passing the ordinary grit traps. It is surprising what a large quantity of foreign bodies are removed by these arrangements. In addition to grit traps and troughs, some factories use what is known as a knottor, the function of which is to remove small knots and any large pieces of guncotton which may have escaped complete pulping.

POACHING.

Washing the guncotton during the pulping is effected in some factories by the use of drum washers fixed to the beating engine; in other factories and at the Royal Gunpowder Factory this washing is done in separate vessels, termed "poachers." The poachers in use at Waltham Abbey hold about 10 hundredweight of guncotton and 1,100 gallons of water, and are fitted with power-driven paddles for agitation purposes. The guncotton receives at least three washings; it is allowed to settle down after each washing, and the washing water is removed by a skimmer. The washing water contains in suspension foreign bodies of a lower specific gravity than guncotton, and in the case of the earlier washing waters, there is always present a scum containing nitro-bodies of low stability.

BLENDING.

A further purpose served by poaching is the thorough blending of a number of different batches. This is a final blending, but at the Royal Gunpowder Factory there exists a regular system of blending right through the whole of the manufacturing process. This system is briefly as follows: The cotton waste reaches the factory in consignments from different contractors. The waste is drawn from store in proportion to the quantities on the contracts, and is mixed and passed through the teasing machine in these proportions.

The next process where blending is possible is in charging the boiling vats. Two vats are filled simultaneously from a number of sets of pans—two pans of each set of four going into one vat; the other two of the set into the other vat. On completion of the boiling, four vats are emptied simultaneously into 32 beaters. This insures the guncotton from the four vats being blended together in the beating process.

On completion of the pulping, the beaters are run alternately into the poachers in such a manner that the contents of the 32 beaters are blended into eight poachers. The guncotton in the eight poachers is therefore uniform throughout.

The system produces guncotton of very uniform nitrogen-content. In the year 1907-8, 291 tests, representing 600 tons of guncotton, gave the following nitrogen result:

Maximum.	Minimum.	Mean.
Per Cent.	Per Cent.	Per Cent.
13.05	12.93	13.0195

MOLDING.

For convenience in drying the pulped guncotton it is molded by light hydraulic pressure into cylinders which measure about 5½ inches in height and 3 inches in diameter. This is effected by running the guncotton pulp into a molding machine provided with a number of holes into each of which fits a hollow plunger. These plungers are connected with a vacuum engine, and a good deal of the water is sucked out of the pulp by their means. The mold block containing the guncotton is transferred to a hydraulic press, and pressure is applied, which has the effect of removing more water and of squeezing the pulp into a condition of sufficient consistency to allow of its being handled with care. In this lightly compressed form a very much larger quantity of guncotton can be dealt with in a drying chamber of any given dimensions than if it is dried in the condition of ordinary pulp, and in its compressed form it possesses the further advantage of being able to be dried on fixed racks. This does away with the necessity and risk of moving drying trays or similar arrangements in a stove. It is also obvious that much less dust is produced.

PRESSING.

If intended for use in torpedoes, mines, or other

demolition work, the guncotton is molded into suitable shapes, as described above, and the molds are then subjected to powerful hydraulic pressure, amounting to about 6 tons on the inch, to produce the finished slabs or primers.

CONCLUSION.

I have endeavored, very imperfectly I am afraid, to give in a comparatively brief time some account of the history of the manufacturing processes involved in the production of guncotton. Other nitrocelluloses, for the manufacture of which some of the processes are slightly modified, have not been touched upon. The subject is a very wide one, and if it were attempted to go into details, each process would require more time devoted to it than has been given to the whole manufacture.

This paper has consisted almost entirely of manufacturing details; very little attempt has been made to deal with the chemical questions involved, and nothing at all has been said about the chemistry of the nitration of cellulose nor of the chemistry of the nitro-cellulose molecule. The published information on both these subjects is very considerable, and is constantly increasing. I had originally intended to attempt a brief summary of the more important papers, but I had to abandon it as quite impracticable. What must, however, strike any manufacturer of nitrocellulose when he consults the literature of the subject, is that the great bulk of it, although of intense interest, is either too theoretical for practical application, or else that the data, being for the most part the result of laboratory experiments, are not always a sure guide

as to what will happen on a manufacturing scale. Our experience at the Royal Gunpowder Factory is, and it is also no doubt the experience of other manufacturers, that all experimental work should be based on sound chemical principles, but to be of practical use it must be conducted on a manufacturing scale wherever possible, and that laboratory work comes in when it is required to ascertain the nature of the results obtained. I venture to think that this is true in the case of several chemical manufactures, and it is most undoubtedly true in the manufacture of guncotton, and I therefore offer the suggestion to any of those chemists who wish to further improvements in the production of guncotton, to take the manufacturer into their confidence, work with him, and to get him to work with them.

T I D A L P O W E R . *

SOME OLD AND NEW TIDAL MOTORS.

BY W. C. HORSNAILL, A.M.I.MECH.E., A.M.I.E.E.

ALMOST everyone interested in the application of power must have wondered, at some time or another, why more advantage is not taken of the ebbing and flowing of the tides around our coasts. The rise and fall of the enormous volume of water surrounding the British Isles would develop enough power to supply the whole kingdom, if only this tidal action could be

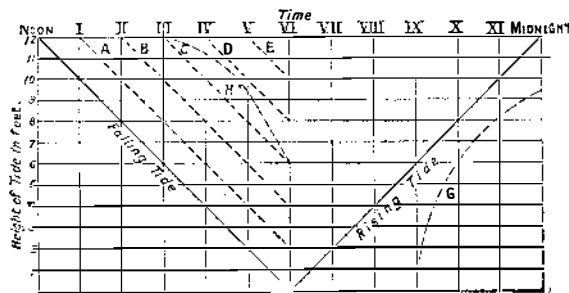


FIG. 1.

fully utilized. Unfortunately, however, certain natural conditions are necessary before we can harness any portion of this waste energy. A reservoir or pound is required to produce a flow of water, and if the cost of constructing the works is to be kept within reasonable limits, the pound can only be formed by building a dam across a natural creek or estuary. These requirements are met with on the shores of many of our estuaries, and to some extent they have been taken advantage of by the erection of tide mills. Old charters show that tidal power was used for grinding corn as early as the eleventh century, and tide mills have been in operation for the same purpose from that time to the present day.

No records exist showing how the earliest tide wheels were arranged, but particulars are available of several mills which were erected in the eighteenth and nineteenth centuries. In the earlier historic mills no attempts were made to produce a fall, the power being obtained from the flow of the water into and out of the pound. To develop power in this way a wheel, similar to the paddlewheels of steamships, was used, but with a reversed action; that is to say, the flow of water drove the wheel. This arrangement entailed the raising and lowering of the wheel to suit the rise and fall of the tide, as only the bottom floats could be immersed if the best results were to be obtained.

A corn mill at one time existed at East Greenwich

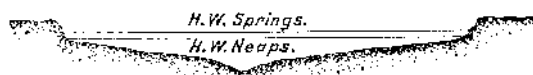


FIG. 2.

which was driven by tidal power in the way we have described. The pound had an area of about 4 acres, and the wheel measured 11 feet in diameter by 26 feet long. The power was transmitted by a bevel gear at either end of the water-wheel shaft, the pinions being free to slide up and down two square vertical spindles. The water-wheel and bevel gears were mounted upon a frame which was caused to rise and fall to suit the tides, and the power was transmitted by either bevel wheel according to which way the water-wheel was running, the other bevel pinion being thrown out of gear. By these means the machinery in the mill was always driven in one direction, in spite of the reversal of the water-wheel at each turn of the tide.

The movable frame, with the water-wheel and gear,

weighed some 20 tons, and the bottom of it was extended to form a kind of shutter, which filled up the opening underneath the wheel race, all the water flowing into or out of the pound being thus compelled to pass through the wheel.

Another type of wheel was devised to overcome the drawback of having to move up and down with the

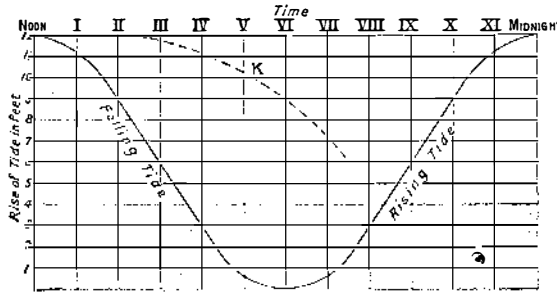


FIG. 3.

tide. This wheel was fitted with hinged floats, which arranged themselves across the stream at the bottom of the periphery, while they traveled through the water edgewise during the remainder of each revolution. With floats of this type the wheel was fixed, and the tide gradually rose over it until in some cases complete immersion took place.

An arrangement of the sluices was also adopted to compel the water to pass through the wheel in the same direction, whether flowing in or out of the pound, thus doing away with the need for reversing gear between the water-wheel and the machinery to be driven.

These wheels must have been very inefficient, as the loss of power caused by the drag of the upper portion when covered was serious, and the design was soon discarded.

Following these earlier mills came the more recent examples, many of which are still in existence, while a few of them may be seen in operation. The older mills aimed at using the current of water caused by tidal action, and advantage was taken of the flow in either direction. The more modern tide wheel is arranged to operate with a considerable fall, and only develops power when the water is flowing out of the pound.

The undershot wheel with straight radial floats is usually adopted, and the mill is started at half ebb or a little later, work being continued for about five hours, or until the water rises under the wheel and chokes the tail race. These arrangements give only five hours of working during each tide, and one naturally asks why the flow into the pound cannot be used as well as the fall outward.

The principles governing the reply to this question will be more easily understood with the aid of the diagrams shown in Fig. 1. The tidal action represented begins at noon, and the period of ebb is taken at six hours; also we have assumed a regular fall for the sake of simplicity. An imaginary pound, 12 feet deep, and having straight sides, will be considered, its capacity being 600 pounds of water, or 100 pounds for every 2 feet.

If the water be run out of the pound at such a rate as will maintain a constant difference of level between the inside and the tide level outside, the fall in the pound may be represented by lines parallel to the tide line. Obviously the water may be run out of the pound under heads varying from nothing to 12 feet, and during periods of six hours to no time at all; it is therefore necessary to consider which head and corresponding time will give the best effect.

The lines A, B, C, D, and E, are drawn in for the purpose of settling this point, and they represent the following results:

A = 100 pounds an hour at 2 feet head, and for five hours = 1,000 foot-pounds.

B = 100 pounds an hour at 4 feet head, and for four hours = 1,600 foot-pounds.

C = 100 pounds an hour at 6 feet head, and for three hours = 1,800 foot-pounds.

D = 100 pounds an hour at 8 feet head, and for two hours = 1,600 foot-pounds.

E = 100 pounds an hour at 10 feet head, and for one hour = 1,000 foot-pounds.

From these figures it will at once be seen that 6 feet of head, or half the total fall, gives the greatest amount of energy.

The next point to decide is whether power can also be obtained from the water running into the pound.

If we attempt to use the inward flow after the tide has risen 6 feet the level will be represented by the line G, and the power will be doubled, but arrangements would be necessary whereby the water remaining in the pound at 6 P. M. could be run out instantly and allow of immediate filling at midnight. In actual practice these requirements would entail enormous sluices to enable the pound to be emptied and filled quickly enough, and either two water-wheels must be used or provision would be necessary to make the water pass the wheel always in the same direction.

Then, again, it must be remembered that our diagram assumes an ideal pound with straight sides and flat bottom, the latter being level with or below low-water mark. The pound to be met with in existing practice is of the section shown in Fig. 2, and the bottom of it, together with the outlet, is usually considerably above the lowest level of the water outside.

When running the water off, this feature offers no difficulty, as during the early part of the working period the level falls more slowly than the tide outside,

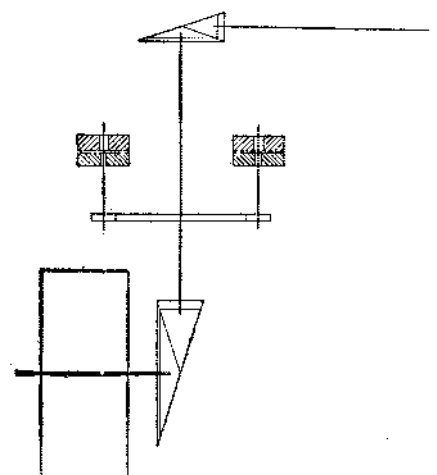


FIG. 4.—MILL GEARING.

and the head increases, the conditions being shown by the line H. If we attempt to reverse the process, as represented by line G, the first 2 feet or 3 feet at the bottom of the pound would fill up very quickly and reduce the head, hence very little power could be developed. Also with a given fall the power depends entirely upon the volume of water, and as the lower half of a pound, having the section shown in Fig. 2, would only contain about 10 per cent of the total capacity very little advantage would follow any attempt to use the water running into it.

It may be urged that the above drawback could be

* The Engineer, London.