Sect. II.—OTHER SELECTED PAPERS.

(*Paper No. 1992.*)

"The Art of making Paper by the Machine, as exemplified in the Manufacture of high-class Writings and Printings."

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The art of paper-making, if not the most important, is at least one of the most useful that has been invented. Paper has, in the present age of rapid advancement and improvement, acquired a degree of importance with which it would not have been credited a century ago. Being the vehicle of written thought between nations as well as individuals, it has contributed more to the advancement of the human race than any other material employed in the arts; and its manufacture constitutes an art depending more closely than any other upon the march of civilization. Its uses are now beyond number, and the demand for it so general that it has become an article of prime necessity, and one that is daily entering more and more largely into the ordinary wants and ordinary life of all classes.

The word "Paper" is derived from the Greek word πάπυρος, a rush which grew in the swamps on the banks of the Nile, about 10 to 12 feet high, and from which the Egyptians manufactured a writing material. The inner cuticles under the coarse exterior portion of the plant were carefully removed, and the thin leaves were laid side by side on a table, moistened with water, and rendered adhesive by the use of a paste made of very fine flour mixed with size or glue. Another layer was laid transversely on the top of the first, and the two were pressed together and dried in the sun, when they became sufficiently cemented to form a sheet. The sheet was then beaten smooth with a mallet, and a surface imparted to it by polishing with a piece of ivory or tooth.

This paper was probably known and used as far back as the third or fourth century B.C., and it continued in general use until the beginning of the sixth century of the present era, when it was superseded by parchment and the paper known as "Carta

Bombycina," made from cotton, which latter was then just being introduced from the East. From the Egyptians, the art of making paper from the papyrus was transmitted to the Romans, who greatly improved it, bestowing more care upon the various operations of washing, pressing, sizing, and smoothing, and they made many different kinds and qualities. The trade in papyrus became considerable, not only at Rome, but throughout the civilized world. The profits from the sale were so large that they produced a revenue sufficient for Firmus, who made himself master of Egypt towards the end of the third century, to boast that he had in his possession as much paper as could support his army. The papyrus, though it was submitted to a special process of manufacture, retained substantially its original form; and it is to the Chinese that the credit is due of having invented the art of making paper from pulp. They were familiar with the art about the beginning of the Christian era, the materials used being the bark of trees, parts of the bamboo cane, rice-straw, and cotton. The Arabians and Hindoos, by their inroads and conquests in Tartary at the close of the seventh century, learned the art from the Chinese. It was next introduced into Europe through Greece and Spain, the Arabs or Moors bringing it with them in their conquest of Spain during the eighth century, and the Greeks acquiring it through their commerce with Asia and Egypt. From Greece and Spain, the art was communicated to Germany, France, and Holland, and thence it reached England. Paper made from cotton, with authentic dates from the tenth and earlier centuries, is preserved, but linen fibre does not seem to have come into use until later, and cannot be traced back further than the middle of the fourteenth century.

The first account of the construction of a paper-mill of any note is the establishment of a large one at Nuremberg in 1390, by Ulman Stromer, a German, in which he employed a great number of persons for the manufacture of paper from linen and cotton fibre. A century afterwards a mill was erected in this country at Stevenage, in Hertfordshire, by Mr. John Tate, to which reference is made in a book printed by Caxton, about the year 1490. In 1588 John Spielman, a German, jeweller to Queen Elizabeth, owned a paper-mill near Dartford, for the erection of which he obtained from the Queen his knighthood, and a 10-year monopoly for the gathering of all rags, &c., necessary for the manufacture. Only very common paper, principally for wrapping purposes, was made there, the finer sorts coming always from France and Holland. About the year 1770, Whatman had the courage to examine, in the capacity of a workman, the continental mills. On his return to

England he founded the mill at Maidstone, which is known at the present day as the manufactory of the finest hand-made paper. Hitherto all paper had been made by hand, sheet by sheet. At the end of the eighteenth century, the idea of a machine, for producing in one operation a continuous web of paper from the prepared pulp, was conceived by a Frenchman named Robert. This machine, developed and rendered practicable in England, soon took up a place of first importance in the paper-trade; and from this time the manufacture was divided into two distinct branches, known respectively as hand-made and machine-made.

Early in the present century, Berthollet discovered the valuable bleaching properties of chlorine, which at once caused a revolution in the trade; manufacturers were able to produce white paper from materials that hitherto had been debarred from use for that purpose owing to their colour. About the year 1844, however, a sudden depreciation arose in the value of white papers, especially the French, due to the indiscriminate use of the bleaching agent. Paper-makers, although appreciating its value, were not aware of the necessity of destroying all traces of chlorine in the prepared pulp. This free chlorine gradually acting upon the fibres, injuriously affected their resisting power, and rendered the paper brittle and wanting in tenacity. Since that time the manufacture has steadily progressed.

Until the end of the eighteenth century, paper was made in Europe almost entirely from rags. At this period other substances were adopted as substitutes, due in part, no doubt, to the insufficient supply of rags, and consequent rise in price. The Author has a copy of a publication, printed by Burton, of London, and said to have been written by Matthias Koops; it was published in the year 1800, and is printed on the first paper made from straw in England. It was dedicated to the reigning sovereign, George III. An appendix is printed on paper made from wood fibre alone, which although hardly properly reduced, is strong, tough, and of a light yellow colour; the printing shows up well upon it, as also upon the straw-paper.

Paper has been made from a great variety of vegetable substances without the use of rags; in fact, almost any vegetable fibre can, by proper manipulation, be made into some sort of paper; but the principal substances which have a marketable value, and are used to any great extent, are esparto, wood, and straw.

Manufacture of Machine-made Paper.

The different processes in the manufacture of machine-made paper are enumerated for treatment as under:—

1. *Materials.*—Linen; cotton, and esparto.

2. *Manufacture.*—Cutting and dusting; boiling; reducing to pulp, under the two heads: breaking, including bleaching and washing; beating. Producing from the prepared pulp a felted web by means of the paper-machine. Sizing, comprising animal and vegetable; glazing; finishing.

Remarks on the Economy of a Paper-mill.

The Author's experience having hitherto been limited to the manufacture of the better classes of writing- and printing-papers, he proposes to give an account of the processes of manufacture as applied to those classes.

1. *Materials.*—One distinguishing feature in the manufacture of paper is that the materials for producing the finished article are either waste from other manufactories, or the private consumer, or substances for which little or no other use has been found, such as esparto fibre, the trade in which is about 190,000 tons per annum, representing in value over £1,200,000.

The main constituent in the structure of all plants is the vegetable fibre or cellulose, which forms the casing or walls of the different cells, being the woody portion of the plant, freed from all foreign substances, and it forms, so to speak, the skeleton of vegetable fibre to the amount of 75 to 78 per cent. Its forms and combinations are extremely varied, but it always consists of the same chemical elements, carbon, hydrogen, and oxygen, and in the same proportions.

Pure cellulose is composed of six parts by weight of carbon, ten of hydrogen, and five of oxygen, C_6, H_{10}, O_5; and this is confirmed by the analyses of different fibres.

Wagner[1] has found them for—

	Flax.	Cotton.	Wood.
C	43·63	43·30	43·87
H	6·21	6·40	6·23
O	50·16	50·30	49·90
	100·00	100·00	100·00

[1] "Handbook of Chemical Technology," by Rudolf Wagner, Ph.D.; edited by Wm. Crookes, F.R.S. London, 1872.

The glutinous, resinous, siliceous and other intercellular matters surrounding the cells together constitute the perfect plant; and it is the object of the paper-maker to eliminate these impurities and to produce the fibre as pure and as strong as possible.

One indispensable condition which this organic substance ought to fulfil above all others, after having been subjected to the action of chemical agents for ridding it of foreign substances, is that it should remain in the form of filaments more or less elongated, and flexible enough to intertwine readily with one another.[1]

Flax, hemp, and cotton rags, having already undergone a process of manufacture, consist of almost pure fibres with the addition of fatty and colouring matters, which can be got rid of by simple boiling under a slight pressure of steam, and the use of an alkaline solution. But the substitutes, being used as they come from the soil, contain all the intercellular matter in its original form, and this has to be destroyed by a strong alkali under a high temperature. The vegetable fibre or cellulose, being of a tougher and stronger nature, is untouched by the action of caustic soda, unless carried too far; while other animal fibres and organic matters are rendered soluble or destroyed by it. The object of the paper-maker, in treating any one particular fibre, is to carry the action of the dissolving and bleaching agents just so far as to obtain the fibre as free from impurities, and as white in colour, as is necessary for the kind of paper he wishes to make from it. The usefulness of a plant for the manufacture of good white paper depends upon the strength and elasticity of its fibres; upon the proportion of cellular tissue contained in them; and upon the ease with which this can be freed from the incrusting and intercellular matters.[2]

A microscopical examination under a low power shows that different fibres are very differently formed. Figs. 1 (p. 256) represent the character of four of the principal fibres used in paper-making, namely linen, cotton, esparto, and wood.

The fibres of linen or flax consist of straight, elongated, cylindrical filaments or tubes, of from 0·157 inch to 2·598 inches in length, and 0·0006 inch to 0·00148 inch in diameter, with tapering extremities. These long fibres have very thick walls, formed of concentric layers of cellulose, endowed with a cohesion which is stronger on the surface than towards the inner walls more recently

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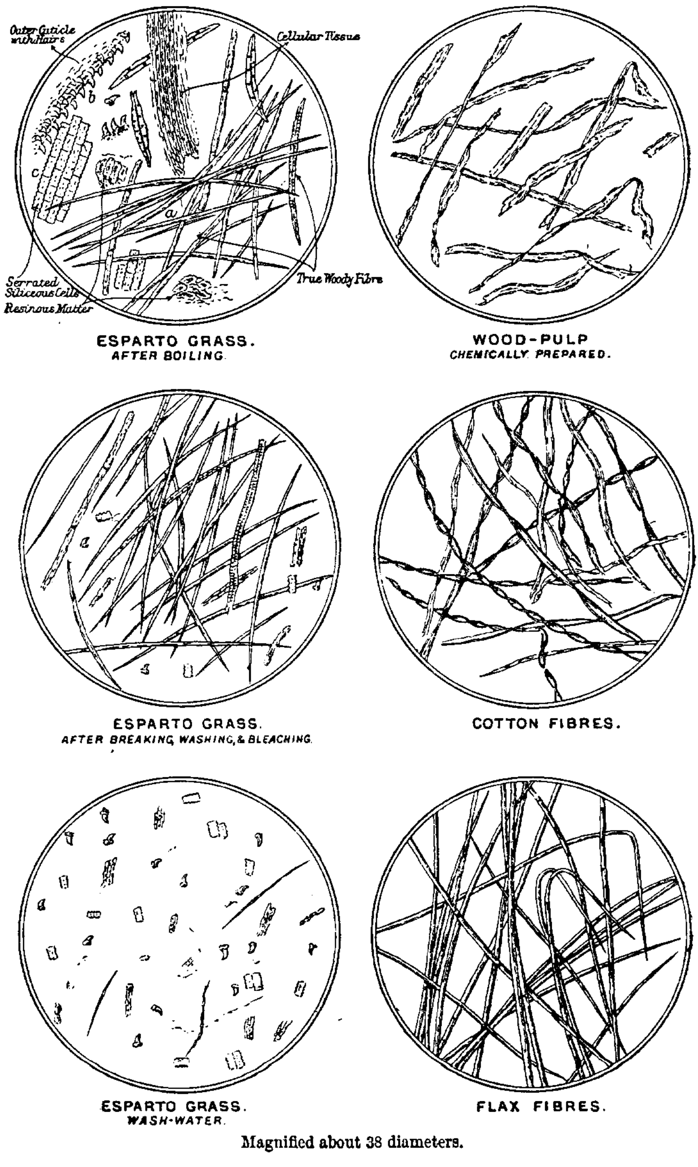
[1] "Succédanés des Chiffons," par M. A. Payen. Paris, 1881.

[2] For a fuller treatise on this complicated substance, see "Le Papier et ses Matières premières," par M. Orioli, read at the meeting of the Industrial Society of Mulhausen, 26th May, 1869.

Figs. 1.

FIBRES EXAMINED MICROSCOPICALLY.



Magnified about 38 diameters.

secreted. They are stiff, tough and elastic, and do not bind or twist together.

The cotton fibres are of a close texture with very thin walls, and have the look of narrow, flat transparent tubes with thickened edges, and twisted several times upon themselves like a corkscrew. They easily bend and interlace one with the other. The length of the fibres varies from 1 to 1½ inch for long-stapled, and from ⅜ to ¾ inch for short-stapled; and their diameter is about 0·00043 to 0·00071 inch.[1] Cotton fibre is a development of the parenchymatous tissue, which is the weakest among the elementary organs of a plant, while the linen fibre is a development of the woody tissue, which is the strongest of such organs. It is, therefore, generally considered that linen only should be used for making the strongest and firmest paper. This may be the case as regards the spinning-fibre, but experience proves that it is by no means the rule in dealing with the bruised fibre for paper-making. With long and careful manipulation in the pulping engines, taking precautions to draw the fibre and not to cut it, new cotton will give a stronger and much closer paper than new linen. The linen fibre, under the beating-rolls, absorbs water more readily than the cotton fibre, and works up into a more "greasy" and wet state necessary for a stiff, firm sheet of finished paper, but it does not with that necessarily develop strength.

After numerous trials to obtain a strong machine-made paper, at which the Author was present, the strongest was produced with new cotton intimately mixed with about one-fifth or one-sixth of its bulk of new linen. As a rule all rag-papers are made with a mixture of linen and cotton, papers of different characters being obtained by varying the proportion of each. The linen fibre should be always slightly longer than the cotton to obtain a close even texture; unless this is done the sheet of paper will look "open," and the two fibres will not work in well with each other. On taking the nature of the two fibres into consideration this would seem to stand to reason; the straight stiff filaments of the linen would not easily mix and interlace with the longer cotton fibres, which latter, being of a flexible nature, twist more readily round the flax fibres as a nucleus.

In illustration of this, Mr. Orioli, in his article on Paper and its Raw Materials, before referred to, makes the following remarks:—

A well-made paper consists essentially of two portions; the

[1] Spons' Encyclopædia of the Industrial Arts, Manufactures and Commercial Products, 1881, p. 959.

one, formed principally by the stiffer pulps, is composed of long and tough fibres, which, in interlacing together, constitute the stoutness of the sheet of paper. They form, so to speak, the woof of the paper. If this portion of the fibres alone formed the sheet it would be irregular, cloudy, and without handle. It is necessary to intermix in the interstices of this woof, apparent even to the eye, much shorter fibres, in order to set off the finished sheet and render it thoroughly close. It is to the presence of these two kinds of fibres, mixed in the desired proportions, that the paper owes at once its bulk, its opacity, its homogeneity, its elasticity, in one word its good manufacture.

The esparto fibre consists of small fine tubes tapering to a point at both ends and very short, being finer and much shorter than those produced from rags. They occur in fibrovascular bundles through the stem of the plant surrounded by a mass of cellular tissue and resinous matter. Their length is from 0·019 inch to 0·137 inch, and their diameter varies from 0·00028 to 0·00072 inch. The true woody fibre takes different forms, the commonest being those marked *a*. They are all cylindrical tubes with thick walls, so thick at times that they become solid. The cellular tissue, being weaker and more easily acted upon by the strong alkali, is easily broken up and in great part washed away in the water from the breaking-engine. The inner surface of the grass is covered with a mass of short, pointed hairs, *b*. The peculiarly serrated cells *c* consist largely of silica; of these it is impossible to get rid of a certain portion, and they appear in the finished paper as transparent spots, especially under a high surface. If the wash-water from the breaking-engines is examined under the microscope, the contents are found to consist, not of true fibre, but of a mass of these siliceous cells, hairs, and small broken bits of cellular tissue.[1]

The peculiar value of this fibre, as contrasted with straw and other similar fibres, which much excel esparto in strength, stiffness and natural impermeability, is the ease with which it is bleached, producing a paper of great whiteness, non-transparent and, when animal-sized, comparing most favourably with that obtained from rags.

The fibres of wood are of a different appearance again. In utilizing wood as a material for paper-making, the primitive

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[1] See an article by Ed. Bevan, published in the *British and Colonial Printer and Stationer*, entitled "The Microscopical Examination of Fibres." "Esparto." Aug. 1, 1881.

fibres or cellulose have to be freed from the woody incrustations which, during the course of vegetation, have gradually thickened, by concentric layers, the inner walls of these fibres. When this is done, they present the appearance of narrow flat ribands with thickened edges, and consist of thin open transparent membranes. The fibres are short and brittle, as compared with those before mentioned, and when used alone, impart their characteristics to the paper made from them, being too short and thick to yield that suppleness so characteristic of rag paper. The woods generally used are the firs and pines, although the pulp produced from the aspen and poplar is very good. Pine gives the strongest pulp, the white pitch pine being most suitable for fine papers. Scotch fir and other kinds of wood, more resinous or less white, yield a very good pulp but with less advantageous produce.

The raw materials used in almost all mills for the higher grades of paper are linen and cotton rags and the esparto fibre. The rags arrive at the mill from the different rag-merchants, either roughly sorted into grades or mixed in quality and material.

There is naturally a great variety of quality and character in the consignments of rags from different countries; and to one who is constantly handling them, it is easy in many cases to tell on examination the part from which they are collected. According to the climate, so is the clothing, heavier or lighter; some nations use more linen, some more cotton; while the collections from large towns are usually whiter and finer in quality than those from the country districts. The Russian supply is almost entirely linen, and that of a very strong and fine quality, although coarsely spun and low in colour. The bulk of the French and Dutch supply is cotton; while in Germany linen has the preponderance. The quality of the new linen and cotton cuttings from Great Britain is much superior to that from abroad—finer, purer, and less adulterated; but the supply of used rags, such as it is, is principally of a low quality, presumably because it is procured from the lowest classes of the population, who alone realise the necessity of turning every penny to account. The French cottons are characterised by their want of bulk and flimsy nature, when new being filled with starch and loading.

Esparto grass (*Stipa Tenacissima* or *Machrochloa Tenacissima*)—so called in Spain, and *Alfa* in Africa, is a spontaneous product of the siliceous and ferruginous soils of Southern and Eastern Spain and North Africa. It is a coarse strong grass growing in rush-like tufts, from 2 to 10 feet in circumference. It is not harvested by mowing, but during summer and autumn in dry weather is pulled by hand from the stems, the roots being left in the ground. The leaves grow to a length of from 6 inches to 3 feet, and are rather flat during growth, becoming dry and curled up at maturity. The leaf is gathered shortly before maturity; if allowed to mature, as is the case when used for making ropes, mats, or carpets, the silica and iron contained in it are more closely combined, and, in consequence, necessitate longer and more costly boiling and bleaching; if, on the other hand, it is gathered too green, the fibres being more or less transparent, would afford a sort of vegetable paper. Lands near the sea coast, at a moderate altitude, exposed to the sun and dry, are most favourable for its growth. Near the coast it is usually shorter and more discoloured, but finer and more tenacious than in the interior, where it is long, thick, and of a brighter colour.

There is a great difference between the two kinds in their behaviour in the mill. The Spanish crop, although shorter, more twisted and less handsome in appearance, is much more easily boiled, with less alkali, and bleaches to a brilliant white. The African crop, on the contrary, which looks greener and straighter, as if not sufficiently matured, wastes much more through the various operations, does not come up in colour, and gives a weaker paper. The Author has seen fine and strong thin bank paper made entirely from the best Spanish esparto.

The following comparison of the value, as a paper-making material, on the one hand of rags, a fibre already manufactured and prepared, and on the other of the esparto grass, an unprepared natural product, may be of interest. Esparto, during the various processes of manufacture, suffers a total loss of about 48·2 per cent., while the average loss on all grades of linen and cotton rags is about 27 per cent.; and the relative value of the two as a manufacturing material is represented by the proportion, 52 to 73. A very different result is obtained, however, if flax and cotton from the raw material be compared with the manufactured paper in the same manner as esparto. Esparto loses about 40 per cent. of its weight in drying, so that 100 lbs. of raw esparto produce about 31·06 lbs. of paper. Out of 100 lbs. of raw picked flax 56 lbs. of retted flax are obtained. From this amount only 9 lbs. of finished yarn are produced. This is again diminished in bleaching to 6·75 lbs. of bleached linen yarn. A further loss of about 25 per cent. in converting into paper reduces the quantity of paper obtained from 100 lbs. of raw flax to only about 5 lbs. Cotton furnishes a better result; 100 lbs. of raw picked seedcotton produces, after ginning to get rid of the seeds, 33·4 lbs. of ginned cotton. From this 29·4 lbs. of white cotton yarn are obtained. There is an additional loss of about 20 per cent. in manufacturing into paper, giving 23·6 lbs. of paper per 100 lbs. of raw cotton.[1]

2. *Manufacture.*—The paper-maker sorts the rags into grades to suit the paper he manufactures. As a general rule, the classes are ranged under the following heads:—linen and cotton; used and unused; bleached and unbleached; old and new colours and prints; blues, &c. These are again subdivided, according to their strength and cleanliness.

The rags, as received at the manufactory, contain sand, dust, and other impurities, which must be separated before passing them on to the boiler, besides their being sorted and cut. They are usually first passed in bulk through an ordinary revolving duster, where they are freed from most of the adhering dust. There are various forms of dusters and thrashers. A good and simple form for preliminary operations consists merely of a square frame, covered with $\frac{1}{4}$-inch wire mesh, revolving on a shaft at a slight incline, and enclosed in a wooden box. The rags travel gradually down the duster, getting well tossed; the light dust is carried up a shaft by a revolving fan, and the heavy particles fall through the meshes into the lower part of the box.

A rag-duster, for giving a final dusting to cut-rags before passing them on to the mill, is represented in Plate 6. It consists of a circular body covered with $\frac{1}{4}$-inch mesh, similar to the square one before described. Lengthways inside the duster planks on end give the rags a good tossing as they revolve; they are so sloped as, at the same time, to push them forward towards the mouth. Before the duster is a rapidly-revolving double "willow," which by its violent action disentangles from the rag all remaining dust and particles. By a suitable mechanical arrangement, the willow is furnished at intervals with a travelling felt carrying the rags, a door being at the same time let down before the mouth of the willow. This allows the rags to receive a good tossing in the willow, and they pass at once into the duster when the door is lifted.

The unsorted rags have to be sorted into the different grades; and all have to be cut to a workable size. The best size is about

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[1] "Cotton" and "Flax," in Encyclopædia Britannica. Ninth edition.

4 inches square, anything much larger than this not working well under the rolls, either passing through too quickly, or rolling up into lumps. Smaller sizes occasion waste of fibre.

The sorting and cutting are done by women standing before square tables covered with coarse wire-cloth of $\frac{1}{4}$-inch mesh, and surrounded by enough baskets or bags to provide one for every grade of rag sorted. The cutting-tables are about 3 feet square, the upper surface being composed of wire-cloth, whilst underneath there is a drawer. A scythe-shaped knife is firmly fixed in a nearly upright position in the centre of the table, with the back towards the worker. The woman cuts the rags by handfuls, and, at the same time, separates from them all buttons, leather, india-rubber, and other foreign substances, as well as small pieces of rag of different qualities overlooked by the sorter. The cut rags should all pass in review on large tables before overseers, as a check on the work of the cutters. Hand-cutting is expensive work, and machines have been designed to perform the same; but, except perhaps for the lowest grades of materials such as ropes, they are in every way inferior. Unless kept very sharp, they are found rather to tear than to cut the rag, thus causing a waste of fibre. Such machines, too, cannot perform the work of selection, or the removal of impurities from the material, which can only be done by close and careful examination at the time of cutting.

All rags contain a small percentage of inherent moisture, varying, according to the fineness of the rag, from 3 to 6 per cent.; it should not be more. The waste occasioned by the dusting, sorting, and cutting, increases with the coarseness and oldness of the material. That in the preliminary dusting and sorting is about 0·4 to 2·0 per cent., and mounts up to even 5 per cent. for very old, coarse and much-worn rags. The waste in the cutting and final dusting varies from 1·0 to 1·3 per cent. for fine new cottons; 2·0 to 4·0 per cent. for coarse white cottons; 1·5 to 2·5 per cent. for fine white linens; 2·5 to 3·0 per cent. for coarse linens; and 4 per cent. and higher for the lower grades. Summing up these results, the following is the total waste of rags from sorting, cutting, and dusting, together with their natural moisture:—4 to 7 per cent. for fine new cottons; 8 to 10 per cent. for coarse white cottons; 5 to 8 per cent. for fine linens; 9 to 12 per cent. for coarse linens; and 14 to 16 per cent. and upwards for the lower grades.

The esparto arrives packed in bales from the harvest-fields in Spain and Africa, and is usually overhauled by women before boiling, who pick out all roots, pieces of heather, &c., that have got mixed with the grass. It is then passed through an ordinary thrashing-machine to free it from dust and sand, and is ready for the boiler.

The process of boiling cleans the rag, destroys the fatty, colouring and other deleterious and extraneous matter surrounding the fibre, and softens the material by decomposing a substance which Prouteaux has called vegetable gluten,[1] and which renders the fibre too stiff to be readily made into paper. These effects are produced by boiling with an alkaline solution under a moderate steam-pressure. The natural products surrounding the fibres in the raw material having already been eliminated in the cotton- and flax-mills, a mere cleansing process suffices to render the fibres fit for conversion into paper.

In former times a peculiar process of fermentation called "rotting" took the place of boiling. The rags were wetted and laid in heaps for a certain length of time, during which fermentation was set up, manifested by the increased temperature of the mass, and by the appearance of a vegetable mould. This method, unprofitable in every way, both as regards waste of time and material, was soon superseded by the boiling process.

Boilers used for cleansing the rags are either rotary or stationary. The advantages claimed for the rotary are—greater uniformity in the boiling, the alkaline ley being able better to intermix thoroughly with the rags owing to the rotary motion; and the more convenient emptying of the boiled rags through a door in the bottom, whereas in the stationary boiler, the lifting of the rags through the door in the top is hard and disagreeable work. The first advantage seems a doubtful one, as there can be no blow-off while the rotary-boiler is in motion, and the same circulation through the material seems to be effected by the entrance of steam at the bottom of the stationary-boiler and its escape at the top; thus having to force its way through the whole mass of rags. That this does occur, and thoroughly, is shown by the fact that frequently fibres and occasionably even small pieces of rag are blown up into the condensing-tank.

The rotary-boiler consists of a wrought-iron cylinder, from 10 to 25 feet long, and about 7 feet in diameter; or more usually it is spherical, about 8 feet in diameter. It is suspended horizontally, and revolves on trunnions driven by gearing. All the working parts must be strong and solid, owing to the great weight

[1] "Guide Pratique de la Fabrication du Papier et du Carton." Par A. Prouteaux. Paris 1864.

of the revolving parts. The steam enters through a stuffing-box in the trunnions.

A simple and efficient form of stationary-boiler is shown in Plate 6. It is dome-shaped, furnished with a steam-pipe passing through the top, down the centre and terminating at the bottom in four or five D-shaped pipes, through which the steam escapes, and forces itself upwards through the rags. Over these pipes and the bottom of the boiler a false bottom of perforated plates is laid to let the water drain off. The blow-off steam can be condensed in a tank of water, which being heated can then be used as feed-water for the lower classes of rags or grass. There must be sufficient water to cover all the rags. After the water and ley from the boiling have been run off, the boiler is filled two or three times with cold water, which is at once run off, to clean the rags. Some of the lowest grades, owing to the amount of alkaline ley used, require a second boiling with water alone, after the first water has been run off. A boiler, such as shown in Plate 6, will take from 12 to 18 cwt. of rags. Steam-pressure of 10 lbs. per square inch is sufficient to boil most rags, and this is economically obtained in a large mill from the back-pressure steam from all the high-pressure workings. The number of hours' boiling depends entirely on the quality of the rag. Cottons need from four to eight hours, and linens from eight to twelve hours.

There are various opinions as regards the kind of alkaline ley to be used. Some manufacturers prefer lime, some soda, and others an alkaline mixture of the two. Pure caustic soda in solution seems to be too strong and violent in action for any except the lowest grades. A causticized solution of soda, produced by the intermixture of carbonate of soda or soda ash with an excess of slaked lime, boiled together, has answered admirably for most grades of rags, a greater or less quantity of the mixture being used according to the quality of the material. A ton of quick-lime slaked and boiled together with 660 lbs. of soda ash, with a sufficient quantity of water to bring the solution to a specific gravity of about 1·06 (12° Twaddell), and taken off in three draughts, supplies a satisfactory mixture. Cotton rags will take seven to eighteen gallons of this mixture to the cwt., and linen fifteen to thirty-five gallons.

In order to reduce esparto fibre from its raw state into a fit condition for manufacture, it has to be freed from all incrusting and intercellular matter. To effect this it is digested with a strong solution of caustic soda under a high temperature. A good form of boiler for esparto (Plate 6), known as Rœckner's Patent, is charged at the top, and the boiled material taken out from a door at the side. The curved pipe at the side, called the "vomiter," is supposed to ensure a thorough circulation of steam and ley through the whole mass. The steam, as well as entering below, is carried in at the top of the boiler, where it issues downwards from a circular pipe through a number of small holes. A depth of 3 or 4 feet of water and the caustic solution are first put in, and brought to the boiling point before charging, or the grass would not be digested rapidly enough to fill the boiler. The pressure is kept at from 35 to 40 lbs. per square inch for the best quality of grass, for three to four hours, during half of which time the maximum pressure is maintained, and is eased off towards the end of the boiling. The strong caustic ley is then run off to a tank, from whence the soda is recovered in the form of black ash. The grass, though very dark in colour, should now be fully digested, soft and short, and it is subjected to a second boil with plain water for about an hour, with a steam-pressure of 12 to 15 lbs. per square inch to wash out the remains of the caustic solution. The boiler is then filled and emptied two or three times with cold water, to thoroughly wash the material and cool the boiler, when the grass is ready.

The above is merely a record of the boiling operation in one particular mill. The steam pressure, amount of ley, &c., varies, of course, in almost every mill. Improvements are now being introduced, and have been adopted in some mills in the boiling, but more especially in the subsequent washing.

The caustic solution is obtained by simply dissolving the crystallized hydrate of soda, Na H O, in boiling water, and allowing the solution to settle. From 15 to 20 lbs. of soda are required to digest 1 cwt. of grass.

It is as well to overhaul the grass in the wet state after boiling to ensure all roots being picked out, as they retain their dark colour and are then more easily seen. This picking occupies a number of hands. As a measure of economy and for more effectively cleansing the material, an ingenious machine, which does away with the necessity of overhauling the grass by hand, has been devised. It is similar to, and on the same principle as, the paper-making machine. By means of this machine, the grass, after being opened out in the breaking-engine, is allowed to flow over a long settling table, where all the heavy impurities fall to the bottom. It is next strained through coarse-cut strainer-plates, and flows over a short wire and through a pair of press-rolls, and leaves the machine with about 50 per cent. of moisture, ready for furnishing to the beating-engine. The loss of the different materials during the process of boiling will be found in the Table in the Appendix, showing the individual and total loss after each operation.

The process of reducing any fibre to a pulp embraces four important operations, namely, washing, breaking, bleaching, and beating. For most classes of papers these four operations are performed in two engines, known respectively as the breaking-engine and the beating-engine. The first three operations of washing, breaking and bleaching, take place in the breaker; the beater being reserved for reducing the pulp to a workable state, "making the paper" as it is called.

The object to be attained in this process, the most important and delicate in the whole manufacture, is simply to produce the fibre in such a pure and finely-divided state as will render it most easily available for making a close, homogeneous, and strong felted web on the paper-machine.

It is necessary clearly to understand the difference between the results to be attained in the two principal operations of this process, namely that of breaking and that of beating. First, as regards rags, these being of a textile nature and the fibres interwoven, require to be drawn out from one another and opened up to allow the water and bleaching agent to act on each individual fibre. This, then, is the object of the breaker—to destroy the identity of the material as rag, and yet to retain the fibre as long as possible; to draw the fibres gradually from the piece or to teaze it out, until none of the original texture is left. The object of the beater is to reduce these fibres to a length suitable for the class of paper to be made from them, and also, by causing them to absorb and carry the water, to beat them into a stiff pulp of sufficient consistency for the paper to be made, and for the requirements of the paper-making machine.

As regards esparto grass, the objects to be attained and the mode of obtaining them, although producing the same result, are very different. The esparto fibre differs much from either linen or cotton, being extremely short, in fact short enough for making paper originally; and being also in the condition of natural fibre not woven into cloth, it only need be broken up and disintegrated. To compensate for the shortness and fineness of the fibres, they require strong beating into a stiff wet pulp to produce a firm and close sheet of paper. Were it not for the necessity of washing and bleaching the material, both the operations of breaking and beating might be performed in one engine, but it is undesirable for high-class papers to introduce into the beater chemicals other than those wanted in the finished paper.

Before the present pulping-engines were invented, rags were reduced to their original fibres by pounding under heavy hammers or stampers. The rags were placed in wooden vats, in which close-fitting mallets were moved up and down by water-power through the medium of levers. A stream of water, supplied from the top and flowing away through a grating in the bottom, kept up a continual washing. The pounding lasted from twelve to twenty hours, until a thorough disintegration and transformation of the rags into pulp had taken place. This process was good in principle, ensured the fibres being retained of full length, prevented any cutting action, and produced strong paper; still, at best, the stuff must have been very unequal and half-cleared. It was a lengthy and cumbersome process, and soon gave way on the advent of the "Holländer." The honour of this invention belongs to the Dutch, who, on account of the insufficiency of their motive-power, the wind, to work heavy stampers, were led to the discovery of cylinders provided with blades to tear the rags. This engine, improved greatly since its introduction a century ago, is now in use in every paper-mill in one form or another. For the lowest classes of papers, such as wrappings, the whole process takes place in one engine; but it does not answer for higher classes, as the rolls and bars, while suitable for opening the material, are not suitable for reducing it to a fine pulp.

In some mills the bleaching is done in a separate engine, known as the "intermediate," or "poacher," the duty of which is either simply to turn the stuff round during bleaching and then to wash it, or else it is furnished with roll and plate to assist the beater. The idea is, that the acids and bleaching agent act on the iron of the engine, bars and plate, causing rust, and the intermediate is therefore made or lined with an acid-proof material such as stone or lead. This idea, although a right one, when put into practice does not compensate in its advantages for the increased space and plant required in the mill; and similar results can be obtained by lining all the exposed ironwork of the breakers with lead, except, of course, the bars of the roll and plate. In mills where the finest classes of writings are manufactured, it is better to have both breaking- and beating-engines, and all the water-pipes lined with lead, to prevent the iron rusting and coming away as spots in the paper. When it is considered that a single speck or spot in a sheet of high-class paper is sufficient to condemn it as perfect paper, and to reduce its value by 10 per cent., it will be readily understood how all-important cleanliness is in every shape and form throughout the manufacture.

It has been the practice in a good many mills to run the "half-stuff," as the pulp is called when it leaves the breaker, broken in and bleached, into stone cisterns or vats fitted with perforated bottoms, the drainage through which could be opened or closed. The half-stuff lay in "steep" in these vats for some hours, to allow the chlorine to have full effect. It was then drained off, the remaining liquor was pressed out by a hydraulic press, and the half-stuff was ready to be furnished into the beaters. This process occasions a waste of time, increased labour, space, and plant in the mill, and also a slight loss of material while draining. It has been found that the colour obtained in the engine direct, is equal to that of stuff that has lain some hours in the steeps, without an increased expenditure of bleaching liquor. What is known as the "direct system," is now coming into frequent use. In this system (Plate 6) the breakers are raised on a platform above the beaters, so as to allow the "half-stuff" when ready to flow down a pipe into the beaters. The superfluous bleach-liquor is got rid of as far as possible by a revolving drum-washer on the breaker.

There are numerous forms of pulping-engines, but the original and most common form is that of an oblong shallow vessel, with circular ends, divided along the centre by a partition or "mid-feather," extending as far as the rectangular part. Across the centre of one half and flush with the bottom of the engine, is fixed the "plate," consisting of a number of parallel steel bars securely bedded in a wooden frame. Above this plate revolves a cylinder, technically called "the roll," round the circumference of which bars of steel are firmly fastened, parallel to the axis or shaft, in bunches or clumps of two together in the breaker, and three in the beater. By the revolutions of the roll upon the bars of the plate the rags are transformed into pulp. The roll can be raised or lowered on the plate by an elevator or lifter, so as to increase or diminish as desired the cutting action of the bars and plate on the material. In front of the roll, the bottom of the engine has a slight slope up to the level of the plate. Behind the roll, it follows the curve of the circumference to a little below the centre of its axis, when it falls gradually back to the original level. This is called the "backfall," because the rags or pulp fall down this slope back into the engine from the buckets of the roll. The duty of the roll is twofold, namely, to tear and cut the material to reduce it to a pulp, and also to act as a lifter or pump to cause the stuff to circulate round the engine. Its action is exactly the reverse of an undershot water-wheel, the space between the bars acting as buckets for lifting the stuff, and discharging it again over the backfall, and it is the only means of circulation.

These engines were formerly made of strong wood, and lined inside with lead or copper; but for many years they have been successfully cast in iron, all in one piece, including the partition or midfeather. For the higher grades of papers, both engines are best lined with lead for the reason before mentioned. For papers used for photographic purposes, in which absolute freedom from iron is required, and in the manufacture of which the raw material is never allowed to come in contact with it, the engines are constructed of stone and lined internally with glazed tiles set flush in cement.

Plans and sections of a good type of engine, constructed by Messrs. George and William Bertram, of Edinburgh, are given in Plate 6; and the details hereinafter mentioned are those suitable for such engines, of a size to turn out from 200 to 250 lbs. of finished paper. The rolls were formerly made of solid wood, preferably of elm; but the use of cast iron has now superseded it. They should be of about 1½ ton to 2 tons weight, the breaker being the heavier. A heavy roll is preferable to a light one, as it is surer in its action, and less liable to spring out of its bearings under extra heavy work.

The bars are sunk and wedged in grooves cast in the periphery of the roll. The best and most effective arrangement of the bars in the roll is to fix them in sets or clumps, and not to space them out equally over the circumference, as they then do not seem to beat so well and thoroughly as when acting together in clumps, although giving the same number of cuts per minute; neither does the stuff travel so well.

The plate on which the roll travels, has to bear its full weight, and the greater part of the work done on the material. It must, therefore, be substantial, strong, and of good material. The steel bars or knives are bolted together and accurately fitted to form a segment of the same circle as the roll; they are fixed in a wooden frame, which lies in a box cast in the bottom of the engine below the roll, and from which it can be easily withdrawn for re-sharpening. The bars of the plate must of course be set at an angle to the fly-bars of the roll, to act as shears in the same manner as a pair of scissors. The greater this angle, the greater will be the cutting action on the material. In the engines in question the angle between the plate and the fly-bars is about 3°. Were the bars of the plate made straight the stuff would have a tendency to travel up to the forward end of the plate, and the work would be unequal. To remedy this the bars are bent in the centre, forming an elbow. The number of bars in the plate varies from ten to twenty-four, and their pitch from $\frac{1}{4}$ inch to $\frac{3}{4}$ inch. To treat rags and strong material satisfactorily it does not answer to have the bars too close together, otherwise the material is drawn through with little effect, and needs too long a time in the engine before being ready, and it is then so "greasy" and "wet," as to be unsuitable for working on the machine. Experiments conducted in a well-known mill in the south of England showed that the best results were obtained in working rags with a pitch of about $\frac{5}{8}$ inch for the breakers, giving twelve bars in a plate, and $\frac{1}{2}$ inch for the beaters, giving fifteen bars to the plate. The bars should not be less than $\frac{1}{4}$ inch thick, and, to obtain the required pitch, they are separated from one another by dividers; these are of zinc in the beater, and of brass in the breakers, to avoid corrosion under the action of the strong chemicals.

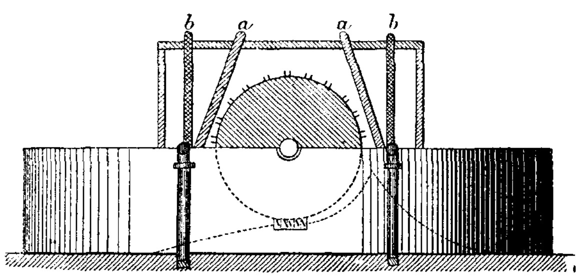
As regards the manipulation of esparto, the fibre is so short and so easily subdivided, that the number and pitch of the bars seems to be of less moment. The Author knows of two mills both working esparto papers, and both turning out a good article; one has twelve bars in the breaker and fifteen in the beater, and the other sixteen in the former and twenty-two in the latter. But as far as the Author's experience goes, he inclines to the opinion that the smaller number of bars produces the best results, opening out the material more easily and quickly, and producing a pulp more workable on the machine.

Plates of brass are sometimes adopted in the beater. Being of a softer material, the action of the knives is less violent and rough on the pulp, and produces a less harsh and more uniform pulp. But the stuff needs longer beating in the engine, and is more liable to become greasy and wet, requiring a lower speed on the making-machine. Where fineness of texture is a desideratum rather than increased output, brass plates might be used to advantage. In some papers, such as photographic paper, where all trace of rust or iron in any form must be excluded, and the paper at the same time uniform in texture, the bars of both roll and plate are made of brass, or of a composition that will not rust.

The speed of the beater-roll is usually about thirty to forty revolutions more per minute than that of the breaker. The work to be done is not nearly so violent; the number of bars in roll and plate is therefore increased, the speed of the roll quickened, and its weight diminished. As a better beaten pulp is produced in a shorter time by a roll revolving quickly than slowly, the number of revolutions have been much increased. From a speed of one hundred and thirty revolutions, or about 1,200 feet per minute for the breaker-roll, and of one hundred and seventy revolutions or 1,550 feet per minute for the beater-roll, the speeds are now increased to as much as one hundred and sixty revolutions, or 1,500 feet per minute for the former, and two hundred revolutions, or 1,800 feet per minute for the latter. These high speeds give the enormous number of 82,800 cuts per minute in the breaker, and 207,000 in the beater.

The rags contain a quantity of sand, dirt, and other small impurities, closely mixed with the fibres, and which cannot be entirely separated from them until they have been opened out under the action of the roll. The small and light particles float on the surface and are borne away with the dirty water; the heavier ones fall to the bottom of the engine, and are conveyed away through a sand-trap consisting of a perforated grating covering a hollow channel cast in the bottom of the engine, and connected with a plug-cock. This trap is situated on the rising slope in front of the roll, where there is the least chance of the water used for washing the half-stuff into the beater disturbing its contents and carrying them down with the stuff.

FIG. 2.



The rolls of the engines are always encased in a wooden cover to prevent the stuff flying about the place. The cover of the washing engine used to have four slits or grooves cut down through the top, two on each side of the roll, Fig. 2. The two slits, *a*, next the cylinder were made for boards of wood to slide on grooves cut in the inside of the cover. These were put in at the commencement, and removed at the close of the washing process.

The other two slits, *b*, contained two frames of very fine copper wire-cloth of about 66 meshes to the inch. The washing process was formerly carried on by the rags or pulp being driven violently upon the wire-cloth frames referred to, by the rapid revolution of the roll; the dirty water flowed away through a pipe down the side of the engine. This plan has been improved upon by the use of a circular drum-washer revolving in the stuff and driven by a belt from the roll-shaft (Plate 6). It is simply a drum covered with fine wire-gauze. Round its shaft is fixed a hollow cone sloping towards the centre of the engine, and at equal intervals on this cone, buckets are fixed which dip into the stuff, discharging their contents down the cone, and through an opening cast in the mid-feather, and connected with a waste-pipe below. This washer is furnished with lifting gear. The beater requires neither washers nor sandtrap, and consequently a much less complex arrangement of discharge-passages and pipes.

Engines are made to hold almost any quantity of paper from 150 lbs. to upwards of 1,000 lbs. of dry pulp. In a mill where one quality, or no great variety, of material is used, and where the machines can run on one class and weight of paper for a long period, a large engine would be an advantage, needing less power, labour, and plant. But where the outturn consists of many qualities and weights, entailing a great variety of material, where the orders are small and various, and the different materials mixed in one paper, smaller engines are a decided advantage, and the economy of the making department is more easily carried on. In working high-classed and expensive papers less supervision and care can be bestowed on the pulp if it is all in one engine instead of being distributed between four and five; and in a large engine the loss is considerably greater in the case of any mischance or accident happening to the pulp. The engines in question hold about 250 lbs. of finished paper. The contents of the breaker must of course be a little larger than those of the beater, as the stuff when in the former is in its raw state, and therefore requires more free space. The proportion should be about 5 to 4.

As soon as the breaker is filled with water, the rags are gradually admitted into the engine before the roll by hand. The roll should never be lowered more than is just necessary to draw the material into fibre, all cutting action being left to the beater. The process of reducing the rags to half-stuff takes from two to four hours, or more, depending partly on the material, but principally on the thickness of paper to be made from it. For thin papers the fibres must be long and very gradually drawn out to obtain the full strength of the material to compensate for their scarcity in the sheet. For the first half-hour or so the roll is raised off the plate, and the rags allowed to wash alone. The sand-trap is open, and most of the sand and heavy impurities left in the rag escape that way. As soon as the water begins to run clear, the sand-trap is closed, and the weight of the roll gradually and slowly brought to bear on the material. In about an hour and a half to two hours the rag should be entirely reduced to fibre, and the water should be running quite clear from the washer. This washing process is a very important one, and needs great care and attention, for mistakes made here can afterwards only be partly rectified in the beater. A badly broken-in engine of half-stuff will never make a close, even, and firm sheet of finished paper. Before the bleaching-liquor is run in, all signs of the textile nature of the material should have been destroyed, so as to enable the chlorine to get at the fibre at once. The roll should now be raised so as just to scrape the plate, in order to teaze out all lumps and threads, and to render the whole a homogeneous mass. The washer being raised and the water-pipe shut, the requisite amount of bleach liquor is run in and allowed to travel round with the stuff until it has brought it to as white a colour as the material will admit of. This occupies from one-quarter of an hour to an hour, depending on the quantities of the rag. Some of the coarser grades require the use of a little alum (about 2 lbs. to the engine) to strengthen the action of the chlorine; and those strongly coloured or very dirty need the application of heat to disengage the bleaching agent more thoroughly, by admitting steam into the engine. Care must be taken not to overheat the stuff, a temperature about lukewarm being sufficient in most cases; overheating tends to weaken the fibre. The heat should not be turned on until the bleach is well mixed with the stuff, as heat liberates chlorine rapidly, and, were the liquor run into an engine already heated, part of the chlorine would be wasted.

Before running the half-stuff into the beater, as much of the chlorine as possible should be washed out from the stuff. Sufficient time should be allowed to give it at least half an hour's good washing. Traces of chlorine will always remain more or less in the stuff, which must be eliminated in the beater by the use of an antichlor. No free chlorine should be allowed to remain in the pulp, otherwise, besides killing any vegetable colouring matter in the paper, it will act on the fibre, and if present in a large quantity will eventually render the paper rotten and brittle.

As previously mentioned, very little work is required to disintegrate esparto grass in the washing-engine or breaker. The roll is therefore lowered until it just touches the plate, at which position it remains throughout the operation. The washing process, in connection with esparto grass, plays a much more important part than with rags. In the latter it amounts to a simple washing and cleansing of the fibres. As has been shown, in dealing with the former fibre microscopically, most of the siliceous particles, outer cuticle and weak cellular tissue of the grass, which is easily broken up by the action of the roll, is carried away by the wash-water. The longer the washing is continued, the better is the colour produced in bleaching, since the wash-water carries away with it that portion of the material which, being less pure than the true woody fibre, opposes greater resistance to the action of the bleaching agent.

In a mill with which the Author is well acquainted, before the direct system was introduced, the grass was washed and bleached in large engines, each operation lasting three hours. The quantity of liquor necessary to bleach it to a good white colour was $11\frac{1}{4}$ gallons per cwt. On the introduction of the direct system, however, the grass could only remain in the breaker as long as the beater, on an average three hours, thus allowing only half the time for each operation. The amount of bleaching liquor then required to produce the same degree of whiteness was $16\frac{1}{2}$ gallons per cwt.

As regards the bleaching and subsequent washing, the grass is treated much in the same way as rag, except that it requires to be heated to a much greater extent to complete the action of the chlorine. A heat of 120° to 130° is sufficient; anything above that is injurious, not only weakening the material but affecting the colour. Before the discovery of the bleaching properties of chlorides and chlorine gas, only the purest and whitest rags could be employed for the manufacture of fine papers. But now the coarsest and most highly coloured materials can by judicious treatment in boiling and bleaching be made to produce paper of a certain degree of whiteness.

The chlorine can be brought to act on the material either directly as gas or through the medium of a solution of bleaching powder. Bleaching by gas has almost entirely given way to bleaching with a solution in the engine, except perhaps as a preliminary operation in mills using the lowest and coarsest materials. This is due principally to the violent action of the gas, which tends to attack the fibres as well as the colouring matters. It is also very offensive and poisonous in the workroom, and as a bleaching solution is as effective in its results, it has been naturally preferred.

The commercial bleaching powder consists of an intimate mixture of hypochlorite of lime and chloride of calcium in the form of a white powder. It is only the hypochlorite, however, which is available for bleaching. Chlorine has a strong affinity for hydrogen, and when it comes into contact with water, the presence of which is always necessary in bleaching, combines with the hydrogen to form hydrochloric acid, liberating the oxygen which, in its nascent state as ozone, oxidises all vegetable substances, and which is therefore the real bleaching element. The solution is easily made in circular vats furnished with revolving agitators, by which the powder is thoroughly stirred up with the water, and all the soluble portion dissolved. The mixture is then allowed to settle, and the clear liquid is run off. The solution as used in the engine will be of a specific gravity of about 1·025, or 5° of Twaddell's hydrometer. The best Spanish esparto requires from 12 to 16 gallons of this solution per cwt. to produce a good white paper; cotton rags take from 3 to 10 gallons per cwt. according to quality; and linen from 10 to 19 gallons. Or with respect to the quantity per cwt. of paper made, which is the best criterion, the amount for grass is 22 to 30 gallons per cwt.; for cotton rags 3 to 11 gallons; and for linen rags from 11 to 24 gallons per cwt.

Sulphuric acid or vitriol, and alum, are used as agents for intensifying the action of the chlorine when dealing with the coarser and more refractory materials. Vitriol should be avoided if possible, unless it can be eliminated afterwards by thorough washing, as it is most detrimental in corroding the machine-wire. Alum or sulphate of alumina is, however, much used, and to advantage. Its liberation of the chlorine being slow and gradual allows the bleaching agent to take full effect on the material.

The process of bleaching occasions a certain amount of waste of the material. Prouteaux estimates it at from 1·5 to 3·5 per cent. for the finer rags, and from 2·8 to 7·5 per cent. for the coarser grades.

The wash-water, or water used in the preparation of the pulp should be as pure, clean, and free from mechanical and chemical impurities as possible. The presence of iron salts is especially detrimental, as the iron is precipitated by the action of the different chemicals in the form of rust, and shows as red spots in the paper. Although the proportion of these salts be insignificant, still the quantity of water that comes in contact with the material is so enormous that the total quantity of iron may be considerable.

Chemical impurities, however, cannot easily be eliminated, the only remedy being the choice of the purest water obtainable for washing. But most of the mechanically suspended matter can and must be separated by filtration. A Table is given in the Appendix comparing the losses on the various grades and classes of rags and esparto, during the several processes through which they have passed.

The further and final reduction of the fibre to pulp, technically known as "beating," together with the addition of size, starch, colour, and other necessary ingredients, is all that now remains to be done before the stuff is ready to pass on to the machine. This last operation is the most important of all, requiring skilful and delicate manipulation, and the greatest care and attention.

Since the best and closest papers are made by a judicious mixture of the different fibres, rather than by the use of one fibre alone, the quantities and quality of each varying according to the character required in the finished paper, it is in this mixture—in blending the different qualities in proportions that shall ensure the paper answering in every respect the purpose for which it is intended—that the paper-maker displays his knowledge and judgment.

As each kind of material, whether linen, cotton, or esparto, whether worn or unused, requires a different manipulation in the engines, the different stuffs are best kept separate throughout the manufacture until they are run into the stuff-chests. Here they are thoroughly incorporated with one another by a slight agitation before passing on to the machine. No rule can be given for the proper admixture of qualities to produce a given paper, nor for the manner of manipulating the fibre in the beater; the only guide is continued and lengthy experience.

In the majority of instances the best classes of rags are used for the finest grades of paper, and the coarser kinds for the lower qualities. By energetic treatment and judicious colouring, it is possible to produce fine-looking paper from the coarser materials; but the excessive waste that occurs, considerably increasing the cost of the material, has to be taken into account. This appearance, besides, is only "doctored," and is never as permanent or so good as that which is inherent in the material.

Printers and typers demand a soft impressionable paper, best obtained by the use of grass and worn fibres, such as old cotton, and quicker beating in the engine. It is pleasanter, however, for writing purposes, to have a firm, stiff, crackling sheet, obtained by the use of more linen and unused rags, and longer and more gradual manipulation in the beater.

Thin papers, again, require longer and stronger fibres than thick papers, to make up by increased strength for their scarcity in the sheet. It is also necessary, in mixing and beating the stuff, to consider the work of the making-machine. Linen fibres absorb and carry water more readily than cotton; gradually and slowly beaten stuff is also much "wetter" than that quickly cut up. If, therefore, a thick paper were made of too much strong linen, and that slowly beaten, it would be impossible to get the water out of it while on the wire, and the paper would become crushed and spoilt at the press rolls, and would not make a uniform sheet.

As a general rule, in treating rags, all the work done on the fibres to reduce them to a pulp suitable for the class of paper to be made, whether in a longer or a shorter time, should be effected gradually, the roll being lowered bit by bit on the plate, so that the fibres are rather drawn out than cut up. The full weight of the roll should not be allowed to come on the fibres longer than is necessary to bring them to a sufficiently fine and even state. The time that this may take will depend upon the sharpness of the bars of the roll and plate, on the speed of the roll, on the material used, and on the time that the stuff has been in the engine. If the work has not been brought on quick enough, and the pulp has been allowed to become what is technically termed "too wet," it will not be possible to get the pulp fine enough in the time; and either it must be sent down to the stuff-chest too long in the fibre, or, if fine enough, so "wet" that the water cannot properly be removed from it while on the machine-wire. In either case the sheet of paper, although firm and strong, will look irregular, uneven, and ugly. On the other hand, if the roll is lowered too quickly on the plate, the stuff will be cut up and will not carry water to put it together on the wire, or be what is termed "fast." The resulting sheet of paper will not only have a poor-looking appearance, but be wanting in strength and firmness.

In the case of esparto, where the fibre is already fine and short, all that is required in the beater is to complete the thorough disintegration of the fibres begun in the breaker, and, by causing the pulp to absorb the water, to render it sufficiently firm and stiff to make the required weight of paper on the machine. For this purpose the engine for treating grass should be furnished very thick—the thicker the better, so long as the grass travels,—and the full weight of the roll is lowered on the plate, and allowed to remain there until the pulp has reached the proper degree of consistency and "wetness."

Before running the pulp into the chest the roll should be raised so as just to brush the plate, and no more, for a few minutes. This serves to "clear the stuff"; that is, it opens up all knots, draws out any irregularly-divided portions, and renders the pulp uniform and clear. A simple expedient is adopted for examining the pulp in the beater, to determine the degree of fineness and uniformity to which it has been brought. A small quantity of the pulp is diluted with a large quantity of water, to render it transparent, in a circular vessel, or hand-bowl of copper or gutta-percha, the darker the colour the better for easier examination. On pouring the contents over the edge of the hand-bowl, the fibres, as they flow over, arrange themselves parallel to the current of water, and their length can be easily examined, and any knots or irregularly-divided portions detected.

The time for which the stuff is allowed to remain in the beater varies greatly, according to the paper to be made. For very thick papers and blottings, an hour and a half to two hours is sufficient; while for bank papers, loans, and very strong papers, four or five hours, and sometimes even twelve hours, are required.

However well the liquor has been washed out of the breaker after bleaching, there will always remain traces of chlorine in the pulp, which, if not neutralized, will act on the fibres and attack the iron of the drying cylinders, forming iron salts, which appear in the paper as rust. It also damages the sizing properties of the engine-size, and is very injurious to animal size, decomposing the glutinous matter and rendering it of no avail.

These traces must be entirely neutralized as soon as the half-stuff is let into the beater, and this is effected by an antichlor such as sulphite or hyposulphite of soda, which takes up the free chlorine in the pulp, forming sulphate of soda and chloride of sodium, or common salt, both of which are soluble. A simple and delicate test, for determining when the chlorine is entirely neutralized, is based upon the peculiar blue colour produced by the contact of free iodine with starch. A mixture of one part of iodide of potassium, two parts of starch, and three of water is used. The chlorine forms, with the potassium, chloride of potassium, liberating the iodine, which, combining with the starch, produces the characteristic blue colour. The object of the starch is to bind together and unite the fibres of the paper, and to render them denser, stiffer, and less spongy; in fact it is used much in the same way and with the same object as for laundry purposes. The usual proportion in the paper is from 2 to 4 per cent., or even more, for the higher classes of writings, where a stiff crackling sheet is desired. The starch is either reduced to a liquid paste with water, and introduced into the engine direct, or mixed with the engine-size; either way it seems to have the same effect. Some paper-makers say that when mixed with the size it improves it, by retarding the precipitation of the resin by the alum, thereby rendering the sizing more uniform.

Falling prices and increased competition have, in the paper-trade, as in most other trades, given rise to adulteration. In paper-making this consists in adding to the pulp kaolin, or China clay, Terra Alba, or precipitated sulphate of lime, or pearl-hardening; all except the last are more or less pure alumina, which increases the weight of the paper at a much less cost than that of raw material. In some cases the addition of a small portion of clay may be an advantage, giving a greater smoothness, softness, and opacity to the paper; but at best it is only a form of adulteration, and if introduced in large quantities renders the paper brittle and weak. Such papers as are used for writing and printing purposes can be made to carry with ease from 10 to 15 per cent. of their weight of clay, and in very thick papers 18 to 20 per cent. In the lower classes, such as wrappings, the loading enters into their composition to the extent of more than 25 per cent. A simple test of the proportion of loading in any given paper is by burning it, and weighing the sheet before, and its ashes after. The weight of the ashes indicates the percentage of this fire-resisting material. In order that the addition of the clay shall deteriorate the quality of the paper as little as possible, the stuff should be drawn carefully in the beater, and sent down to the machine longer and wetter in the fibre than if the paper were to be made with no loading. The want of strength in the clay must be remedied, as far as possible, by the increased strength and length of the fibres. The more finely divided the clay can be introduced into the pulp, the better will it mix and adhere to the fibres, and less of it will be carried away by the waste-water from the machine-wire. A good method of preparing the clay for the engine is as follows. The loading is first mixed with powdered starch, in the proportion of 1 cwt. of starch per ton of clay, in circular mixers fitted with revolving agitators. When thoroughly incorporated, the mixture is strained through a "search" into another series of mixers furnished with steam-pipes. The mixture is here boiled, which not only assists in thoroughly disintegrating the clay, but also keeps it in a better state of suspension in the water. The loading should be mixed with the pulp before the addition of the engine-size, which then appears to envelop the fibre and loading together, and enables the paper to hold it better.

Whatever quality of material is used in the manufacture, and however well it has been bleached, the finished paper will always have a more or less yellowish tinge. In some of the higher classes this pure natural colour is preferred, and the paper is allowed to retain it; but as a rule, all papers are toned to produce as pure a white as the quality of the material will admit. The colour recognized as white is made up of the combination, in their proper proportions, of the rays of the three primary colours, yellow, red, and blue. The pulp has naturally a yellowish tinge; if, therefore, the necessary quantities of red and blue, in the form of pigments, are added, the desired white shade will be produced. In the higher class papers the colours used for this purpose are, ultramarine blue and carmine, the former a dry, deep blue powder, and the latter a liquid produced by the mixture of carnation paste, ammonia, cream of tartar, and water, in the following proportions:—Carnation paste, 54 lbs.; liquid ammonia, 7 lbs.; cream of tartar, 9 ozs.; water, 36 gallons. In addition to these two colours, a great variety of others is required in the manufacture of papers of different tints, all of which, with one or two exceptions, must be mixed with the pulp in the engine. It is not the object of this Paper to deal with the colouring of the pulp, which embraces a considerable knowledge of the different pigments and their proper admixture, and which comes more under the province of the colour-man than the paper-maker.

Besides these materials, more or less "engine-size" has to be added to the pulp to render the paper non-absorbent of ink. It consists of a resinous alumina, which adheres to and envelops the fibres, and is precipitated by the addition of alum or sulphate of alumina to a soap of resin. But this will be dealt with more fully when comparing the respective merits of animal-sized and engine-sized papers.

From the beaters the pulp flows down leaden pipes into the large circular vats or closets, known as "stuff-chests." They hold from 1,000 to 2,000 lbs. of pulp, which is pumped from them up to the machine. Each machine should be provided with at least two of these chests, so that, when one is in use, the other is empty and ready for a fresh supply of pulp from the beaters. They can be constructed of stone, or concrete rendered with cement; and are furnished with a very slowly-revolving agitator, just sufficient to keep the pulp in motion, and prevent settlement of the heavier portions.

The main object of the paper-making machine is to produce from the prepared pulp a close, even and firm felted and continuous web of paper of any desired width and weight. The various operations performed on the pulp by this machine may be classed as follows:—Settling, or extracting from it, as far as possible by settlement, all dust, sand, and foreign substances that are still contained in the pulp. Straining, to keep back all knots, threads, and light impurities from passing on to the wire, and thus to render the pulp more uniform. Interlacing the fibres of the pulp together on the machine-wire, by means of water and lateral shake. Giving the character to the paper by the impression of the "dandy-roll." Extracting the water from the web by a strong natural suction. "Couching" the web, to press out most of the remaining water, and to squeeze the pulp into a felted web, between heavy felt-covered rolls. Pressing the web between brass and felt-covered rollers. Drying the web over revolving cylinders filled with steam. The actual operation of forming the paper begins as soon as the pulp reaches the wire, and is completed after the web has left the couch-roll. All the other steps are subsidiary operations; and it is here where the greatest care and attention have to be paid, and where experience is demanded.

As previously mentioned, there are two distinct processes of producing the finished paper from the prepared pulp, known respectively as hand-made and machine-made. Hand-made paper, except for certain of the best classes, has been almost superseded by machine-made, the expense of manufacture, and consequent high price, rendering it too costly for ordinary use. In making paper by hand the pulp, diluted with a sufficient quantity of water, which is used throughout the manufacture as a means of carrying the material through the different processes to which it is submitted, is emptied into a vat. The paper-maker or vat-man, standing alongside this vat, dips a mould into the pulp and takes out a sufficient quantity to form a sheet of paper. The mould consists of a wooden frame, covered over the bottom with a fine wire-cloth, and surrounded by an elevated border on the top, called the "deckel," which determines the size of the sheet. The texture of the wire-cloth gives to the paper its character, whether laid or ribbed, or wove, or watermarked. While the water is straining through the wire, the man shakes the frame to and fro in every direction to interlace the fibres thoroughly together, and distribute the pulp as uniformly as possible over the surface of the mould. When the sheet is formed, the deckel is removed, and the "coucher" takes the mould and applies a felt to the sheet, and by a dexterous turn lays the whole sheet upon it and gives back the mould to the vat-man. This is called "couching the sheet." On this is placed another felt, and then a fresh sheet from the mould, and so on, until a pile is accumulated, called a "post" or "bale," consisting of about eight quires or one hundred and ninety-two sheets. The post completed, it is placed under a hydraulic press, and subjected to a considerable pressure to force the water out. When sufficiently pressed, the work of a third hand, called the "layman," begins, who takes the sheets carefully from the felts and lays them into a post of themselves. In some mills the sheets are now taken to the drying loft, but if a superior quality of paper is desired, it is necessary to lift and exchange the leaves. In the exchange, the leaves of two posts are lifted one by one and formed into a fresh post, in such a manner that their position in the pile is changed. After four or five operations of this nature, alternately with a gradually increasing pressure, the leaves are hung up in a loft to dry. This repeated exchange and pressure is said to give the characteristic mellowness and velvety feel to hand-made paper.[1] When dry the sheets are sized, being passed by hand between felts through a solution of animal glue well heated, which thoroughly penetrates the paper. The sheets are then hung up again to dry, and then flattened out and glazed between rollers.

This process is a slow and laborious one. In the year 1798 at the French mill at Essonne, a man named Louis Robert, conceived the idea of a machine for producing a continuous sheet of paper. A patent was granted to him, and a reward of 8,000 francs by the French Government. Owing, however, to the disordered state of the country at that time, Robert was unable to bring his ideas to perfection, and Mr. Leger-Didot, proprietor of the mill, bought the patent from Robert, and went over to England in search of some one to work out the idea with him. Mr. Fourdrinier, proprietor of the Dartford mill, got hold of it, and, aided by the mechanical knowledge of Mr. Donkin, after patient toil and perseverance, attended with great expense, for which he received no recompense, succeeded in 1803 in building a machine, which worked tolerably well.

This machine, by the subsequent improvements of Dickinson, Causon, Crompton, and others, has been brought to the state in which it now is, and may truly be said to be one of the most beautiful combinations of mechanism yet invented (Plate 7). It embraces a multitude of the most ingenious and delicate opera-

[1] "Guide Pratique de la Fabrication du Papier et du Carton." Par A. Prouteaux. Paris, 1864.

tions, and produces in a few minutes, and in one process, from the prepared pulp, sheets of paper ready to be baled up for the market. As before stated, it has almost driven hand-made paper from the market. Still, as is almost invariably the case where a hand-made and a machine process are compared, there are points in the former which it is impossible to imitate in the latter; and probably hand-made paper will always find a market.

There is a strength and smoothness, a pleasant glossiness of surface in hand-made paper, which has not yet been imitated by the machine. This is probably due, in part, to the more complete interlacing of the fibres by the hand-shake than by the machine-shake; in part, also, to more time being allowed for the water to drain off the wire, thus enabling the pulp to be beaten longer and wetter in the fibre. Nor is it possible on the machine to imitate the heavy and continuous pressure to which the sheets in hand-made paper are subjected—a pressure which is said to impart the characteristic firmness and smoothness to hand-made paper, and which is not equalled by the corresponding process on the machine of passing the web between felt-covered rolls. Lastly, the continual state of tension of the web on the machine between the various press-rolls and drying cylinders—a tension that is increased by the contraction of the paper in drying—must draw the fibres apart from one another, and weaken the strength and firmness of the sheet. Certain special papers, such as bank-notes, stamp-papers, deeds, in one word, all papers in which durability is the chief requirement, are better adapted to the vat than to the machine. On the other hand, the machine is peculiarly suited for making thin papers, which are not easily made by hand without risk of great damage in the couching department from the difficulty in transferring the sheet whole to the felt. The entire process on the machine occupies at most only a few minutes, which, in the ordinary state of the weather, could not be done in less than a week by hand.

On Plate 7 are given the plan and elevation of a 96-inch machine, made by Messrs. James Bertram and Son, Edinburgh. The stuff-chests are usually sunk into the ground to allow the pulp to flow from the beaters. It is then pumped up on to the screen or sand-table. For this purpose an ordinary plunger-pump, fitted with ball or Perraux valves, is most suitable, all the metal coming in contact with the stuff being of brass or brass-lined.

The following diagrams and description of the Perraux valve and pump are taken from a paper entitled "L'industrie du papier à l'exposition de Vienne." The valve, Fig. 3 (p. 284), is of gutta-percha; the piston, Fig. 4, is of cylindrical form in its lower part, and divided into two lips terminating in a point. This conical part is flattened and split at the top in such a manner that, under a pressure from above, the two lips are closely shut one against the other, and permit the pulp to be forced up. A valve of the same nature at the lower part of the pumps, or at the end of the pipe from the stuff-chest, acts in the same way as an ordinary force-pump. This arrangement answers admirably for pumping semi-fluid substances like paper-pulp.

Fig. 3.

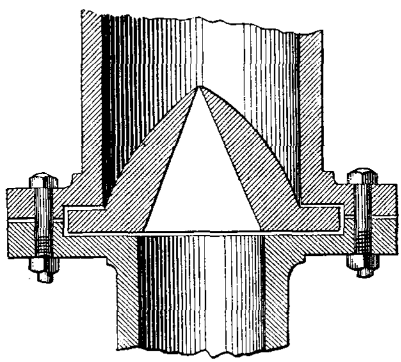
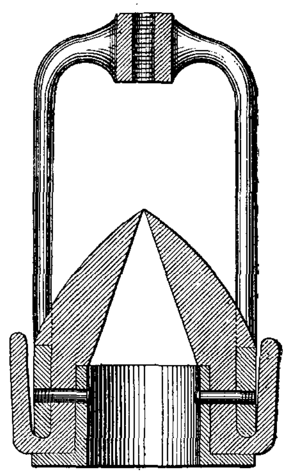


Fig. 4.



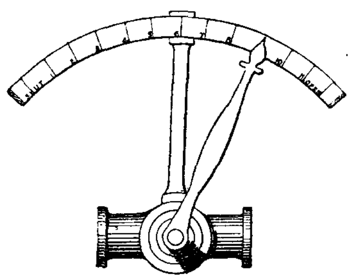
The stuff-pump discharges into a long upright box. At the bottom of the box a small sluice, worked by a screw, regulates the supply of pulp to the machine. There is also an overflow-pipe in the box taking back into the chest all the surplus. Since the pulp, as let down from the beaters, is never sufficiently diluted for working, there is also another box or tank supplied with water by a separate pump, with sluice and discharge-pipe for regulating the supply to the pulp. The water and pulp mix together, and flow on to the screen or sand-table. This consists of an elevated table, in which is sunk a shallow serpentine channel lined on the bottom with rough felt, and divided throughout its length by a number of small weirs, behind which the impurities settle and collect as the pulp flows over them on its way to the strainer. These sand-tables should be frequently cleaned and washed out, especially when working on low-classed papers.

The strainers or knotters consist of plates of brass or some hard and durable composition, about $\frac{1}{4}$-inch to $\frac{3}{8}$-inch thick, with fine parallel slits cut in them through which the stuff passes, all knots and improperly divided portions remaining behind. They can be made to act in two ways, by vibration or by suction, or sometimes a combination of the two. For fine writings, where the stuff is carefully watched and prepared in the beating-engine, one straining through a finely cut suction-strainer is sufficient. The suction-strainer consists usually of a box covered with square or circular plates. This revolves in a square vat containing the pulp made to pass through the plates by strong suction. The interior of the box is connected through a stuffing-gland with a pipe leading to the breast of the machine. The suction is obtained by the rapid vibration of a series of leather or india-rubber bellows fitted in the centre of the strainer, and driven, at a high speed, by suitable crank-gearing from the outside. A great improvement on this method of obtaining suction, both as regards quietness in working and saving of wear and tear, has been brought out by Messrs. James Bertram and Sons, of Edinburgh. It is produced in each strainer by an air-pump operating upon a flexible sheet, carried on a frame inside the strainer, and lying parallel with each side of the plates. The pulp never enters the pump, and only touches the flexible sheet before passing out at the delivery-box. (Plate 7.) Each machine should be provided with at least two strainers, and, perhaps, one of a larger cut suitable for working a different class of pulp.

From the strainers the pulp passes on to the wire of the machine. One of the first duties of the man on starting the machine is to adjust the amount of pulp flowing on to the wire, to produce the required weight of paper at the end of the machine. To accomplish this the foreman takes a piece of the paper as it leaves the last drying cylinder, and, cutting it to the required size, weighs it. If it is too heavy, the sluice at the bottom of the pulp-box must be closed a little, or the speed of the machine quickened, or *vice versâ*. He does one or other according to the character of the pulp, driving the machine as quickly as is consistent with producing good paper. Since it is impossible for the machine-man to be sure of the weight until a considerable amount of paper has passed over the machine, it is obvious that the means for raising and lowering the sluice of the pulp-box should be as delicate as possible, so that the man may be able to adjust the weight at once to a nicety. The sluice is generally worked by a fine screw; but the Author has seen a neat contrivance for effecting greater accuracy in its adjustment. It consists of an ordinary horizontal plug-cock (Fig. 5) in the bottom of the pulp-box, to the plug of which is fastened a long arm or pointer, marking on a graduated arc the amount of opening of the sluice.

The wire consists of a continuous woven brass cloth, supported horizontally by a series of small "tube-rolls" in a frame. It is stretched tight over two rolls, one at each end of the frame, called the "breast-roll" and the "lower couch-roll," which should be made rigid enough not to yield at all under the excessive tension. The ordinary gauge for the wire is 66 meshes to the inch for writings and printings. Finer wires are used, however, up to 80 to the inch. For lower grades the mesh is coarser.

Fig. 5.



As much water should be abstracted from the web as possible while on the wire. It passes through the meshes of the wire at the lines of contact between it and the tube-rolls. These latter should therefore be numerous. The water flowing from the wire, which contains a considerable percentage of fibre, especially from finely beaten pulps, drops into a flat copper-vat, from which it flows into a tank, and is pumped up with the water for diluting the pulp, so that none of it shall be wasted.

From the tube-rolls the wire conveys the pulp over a pair of suction-boxes for extracting the remaining water from the web, and then between a pair of heavy felt-covered couch-rolls, after which the web leaves it. The wire, passing round the lower couch-roll, is carried back to the breast-roll over a number of small wooden-rollers.

The width of the web of paper is determined by two continuous straps of vulcanized rubber about 1½ inch square, one on each side of the wire, called the "deckel-straps." The distance between these straps, which travel along the wire and at the same speed, can be increased or diminished. They run over flanged brass pulleys, and guide the pulp from the moment it spreads on the wire until it arrives at the first suction-box, where the web is sufficiently dry to retain its edges.

The frame of the machine, from the breast-roll to the first suction-box, is hung on a pair of strong hinges, and is capable of a slight horizontal motion, imparted by a horizontal connecting-rod, one end of which is eccentrically keyed on to the face of a rapidly revolving disk driven by a pair of speed-cones, so that the speed of the shake can be altered. This motion, therefore, known as the "shake," is greatest at the breast-roll and decreases as the pulp travels along the wire. It is at most very slight, about $\frac{1}{8}$ inch more or less.

The principle object of this shake is to interlace the fibres together; but it also assists in keeping the water from passing through the wire too rapidly before the paper has been properly formed. This shake and water are the two great factors by means of which the machine-man forms the paper; and he must so regulate the two as to make the closest and best looking sheet of paper possible from the pulp. It is evident that the shake will have little or no effect on the fibres unless they are floating in water, and therefore the water must be prevented leaving the pulp before the shake has done its work. The more rapid the shake, the less quickly will the water leave the wire; and the slower the shake, the easier will the water pass through it. If there is sufficient shake to interlace the fibres together, and the pulp still looks dry on the wire, more water must be added by opening the sluice at the bottom of the water-box. This is characteristic of quickly beaten, or "fast" stuff. Again, there may be as much water in the pulp itself as can be taken from it by the drainage from the wire and the suction-boxes, and if the sheet of paper looks wild and open, a little more shake may be necessary to close it better; this is generally the character of long and wet stuff. Much discretion must therefore be exercised, in regulating the amount of shake and the quantity of water, to suit the character of the pulp. The speed at which the machine is driven must be also taken into consideration. The quicker the speed, the less time will there be for the shake to form the paper and for the water to leave the pulp; and in some cases, in dealing with "wet" pulps or the thicker weights of paper, the speed of the machine must be diminished. No rule can be given for this, as the character of different pulps, depending partly on the admixture of material, and partly on the mode of manipulation in the beating-engine, varies so greatly, and sometimes in so unaccountable a manner, that experience can be the only guide.

As regards the length of the wire-cloth, it is evident that the greater the distance between the breast and the suction-box, the longer time will there be to shake the pulp together, or in other words the quicker can the machine be driven. Since it has become possible to weave wires 50 feet long, this distance has been much increased on machines, and is now generally not less than 11 or 12 feet.

The water that will not leave the pulp on the wire must be taken from it by suction. Most machines have two suction-boxes with the "dandy-roll" revolving between them; so-called because it can be made to give to the paper any desired appearance. The web, to receive and retain any mark or character, must neither be in too dry nor in too wet a state, but just moist enough to be capable of receiving a clear impression, and just sufficiently dry to retain that impression permanently. The first suction-box regulates the amount of moisture in the web necessary to give a clear impression, the remaining moisture being extracted by the second. The suction-boxes are of wood or metal, and air-tight, having no communication with the air except through the wire. The water is drawn into them by suction-pumps as the web passes over. The boxes are fitted at each end with movable air-tight heads, adjustable with the deckel-straps, so that the space between them and the width of the web is the same.

The process of water-marking machine-made paper was for some time considered an impossibility; but it is now effectually and ingeniously accomplished. The dandy-roll, a light cylinder consisting of a narrow brass-tube, on which are soldered a number of brass rings or spiders of about 4 to 6 inches in diameter, is placed in framings so as to rest across and upon the wire-cloth, and to be moved by it. The cylinder is covered with wire-cloth, wove or laid or linear, on which small pieces of wire are soldered representing the letters or devices to be reproduced in the web. From the second vacuum-box the web passes between the couch-rolls, so called from the corresponding operation of couching in hand-made paper, which, by pressing out most of the remaining moisture, impart sufficient consistency to the paper to enable it to leave the wire. Both rolls are covered with a felt-jacket, and the top one is provided with levers and weights to increase or diminish the pressure on the web.

The paper is now fully formed, and passes between one pair or preferably two pairs of press-rolls to extract the remaining moisture, and to obliterate as much as possible the impression of the wire-cloth from the under side of the web. It is carried from the couch-roll by a travelling felt through the rolls of the first or "wet-press." The rolls are of cast-iron cased with a brass-shell shrunk on; the pressure between them on the web can be increased by a screw-press acting on the journals at each end of the top roll. In the first press the upper surface of the web is in contact with the brass, and is therefore rendered smoother than the lower surface which rests on the felt. As it is important that both surfaces of the paper shall be nearly alike, the action of the first press must be reversed in the second, the felt being in contact with the upper and the brass with the under surface.

The paper is finally dried by passing it over a series of hollow cast-iron cylinders heated with steam, and driven one from the other by gearing. The slower and more gradual the drying process, the better, as the change on the fibres of the web due to the rapid contraction is thereby not so excessive, and the heat required at one time is not so great nor so likely to damage the quality of the paper. The heating-surface should therefore be as large as possible. A great number of cylinders is required now that machines are driven at such high speeds. The usual number is from ten to twelve, of from 3 to 4 feet in diameter, giving a heating-surface of from 120 to 140 square feet per foot width of web. If much larger in diameter, too great a proportion of heat would be lost by radiation from the ends. The cylinders are so placed that both surfaces of the web are alternately in contact with the heating-surface.

All the cylinders, except the first two or three with which the moist paper comes in contact, and where the greatest evaporation occurs, are encased with felts. The object of these felts is principally to keep the web of paper flat against the drying-surface and to prevent wrinkling; provided the paper is not too moist, nor too rapidly passed over the cylinders, these felts also assist in the drying if they have time to become dry while passing back again to the first cylinder. To assist the drying of the felts in machines made to travel at high speeds, they pass over, in their return journey, small cylinders filled with steam.

The usual mode of heating the cylinders is by a branch pipe to each from a main steam-pipe extending alongside the machine. By this method the amount of heat apportioned to each is regulated by a cock. The best method of drying the paper would seem to be to extract an equal amount of moisture at each cylinder as the paper is moved along, so that the first cylinder reached by the paper should be the coolest and the last the hottest. It needs only a slight heat to dry a damp sheet, but, as the paper dries, it would take a greater degree of heat to evaporate the remaining moisture in the same time. With a separate steam-pipe to each cylinder it would be difficult for the machine-man to keep them at a gradually increasing temperature; and it would seem a better plan to lead the steam directly only into the last one, and to allow it to exhaust from one to the other. This would ensure the temperature decreasing gradually to the first drying cylinder. The drying of the paper is costly, necessitating a considerable expenditure on fuel. Hoffmann, in his treatise on paper-making, asserts that it has been found by theoretic calculation, as well as from experience, that about ½ lb. of coal is required to produce steam enough to dry 1 lb. of paper.[1]

The web of paper, in passing from the couch-roll through the press-rolls and over the drying-cylinders, is in a state of continuous tension; this is increased considerably by its tendency to contract in drying which is forcibly prevented. The paper is, however, free to contract across the web, and the web measures from 1½ inch to 3 inches wider on the wire than it does at the end of the machine. Papers of different materials, and more particularly of different weights, stretch more or less between the different presses. For thin papers the presses require to be driven a little faster to prevent the web creasing under the roll; but a similar degree of tension would break the web if applied to thick papers. In working different weights and classes of paper, therefore, the relative speed of the different parts may have to vary slightly. This is especially the case with water-marked papers, where the distance between each impression must be of a given length and remain constant. The variation of speed is usually effected by laying strips of felt or canvas, smeared with resin, on the driving-pulley of the part to be accelerated. This is a rough expedient and, if expansion-pulleys could be designed of simple construction and easily worked while the machine is in motion, they would be a great addition to it.

The web of paper when dried is wound up in long reels over wooden cores, impelled by gearing through the medium of a friction-pulley, so that the reel, driven by friction only, decreases in its number of revolutions as the diameter of the roll of paper increases.

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[1] "A Practical Treatise on the Manufacture of Paper in all its branches," by Carl Hoffmann, 1873.

The average speed of a paper-machine on fine writings of medium weight is from 60 to 70 feet per minute, but on thinner weights, the machine can be driven up to 120 feet per minute. It is, of course, the object of the paper-makers to obtain as high a speed as possible, consistent with making a good sheet of paper, as it costs little more to drive it at 80 feet a minute than at 40 feet; whereas twice the amount of paper is made at the higher speed. The speed of the machine has frequently to be altered while in motion. An alteration of a few feet a minute can be effected by changing the driving-speed of the steam-engine governor; for a greater change, the machine must be stopped, and other driving-wheels substituted, unless it is provided with a pair of high-speed cones, giving with any one set of driving-wheels speeds varying 40 to 50 feet a minute. All the different parts of the machine proper should change in speed together, so that they shall always preserve the same ratio of motion one to the other. The stuff-chests and pumps, strainers and suction-pumps are driven direct at a constant speed from the steam-engine.

Paper for writing and printing must be non-absorbent of ink, or it would partake of the nature of blotting-paper. To render the fibres non-absorbent, some form of animal or vegetable size or glue must be applied to the paper, either as a coating on the finished web or mixed with the pulp in the beating-engine. The former process is known as "animal or tub-sizing," and the latter as "engine-sizing."

Animal-size is prepared principally from the waste cuttings and clippings of hides of oxen and bullocks of no use to the leather-merchants, and consisting of horn-piths, heads, tails, legs and belly-pieces. The methods of extraction of the size are, with various improvements, much the same now as those employed years ago; namely, soaking in boiling or almost boiling water until all the gelatine has been extracted. The hide-pieces, "scrolls" or "scrows," are first soaked in cold water to soften them, and are then cut into shavings in a machine similar to an ordinary revolving chaff-cutter. The size is obtained much quicker and better when the scrows are cut into shavings than when boiled in the piece, since they present, as shavings, a greater extent of surface to the action of the heat. It requires a higher temperature and a much longer boiling to produce size from the piece, and this tends to deteriorate its quality. Formerly, in order to facilitate the extraction of the size, the scrows were soaked in water until incipient putrefaction set in, when they were put into the boiler. In order to keep this rotten size from further putrefaction, sulphurous acid was mixed with the scrows, but this is very liable to injure its sizing properties. All these drawbacks have been overcome by cutting the hide-pieces into shavings before boiling.

After cutting, the shavings should be steeped again for some hours in cold water to swell them out and to render them thoroughly soft, so that the size may be extracted as soon as heat is applied. The object is so to prepare the scrows as to produce the size in as short a time and at as low a temperature as possible. The shavings are next put into a wooden tub fitted with a false perforated wooden bottom on which the scrows rest. Underneath the false bottom is a closed steam-coil to supply the heat. The scrows are covered with hot water, which is kept at a temperature of from 175° to 190°, depending on the kind of scrow. In about from four to six hours sufficient gelatine should have been extracted to take off a draught; and the decoction is strained off and fresh water added to the scrows. In this manner four or five draughts can be taken from one lot of clippings which are all mixed together in cisterns and allowed to cool into a jelly ready for use.

A ton of good hide-clippings will produce from 2,100 to 2,600 gallons of size, which, when diluted to a working consistency, is increased to from 2,500 to 3,100 gallons; this quantity will size from 24,000 to 48,000 lbs. of paper already about one-third sized in the engine, depending upon the thickness of paper. About 10 lbs. of alum should be added to every 100 gallons of size to preserve it from decomposing; it also diminishes the solubility of the gelatine and renders the paper sized more impermeable. To prepare the size for use it is remelted at a temperature of 115° to 120°, and diluted with water, if necessary, to such a consistency as suits the paper best for which it is to be used. Thin or open porous papers need a stronger size than thick and firm papers.

The old plan of sizing, employed still for hand-made paper, of dipping the sheets of paper into a vat filled with hot size, and then slowly drying by hanging them on rope lines or "tribbles" in a loft, is adopted in machine-mills for the better kinds of paper used for office-books, ledgers, &c., where the size has to withstand the action of strong chemicals such as red ink, and also to allow of easy erasure. The sheets remain a longer time in the size which penetrates more into the body of the paper, and they are also able to expand and contract freely in drying, which produces a stronger and firmer-sized sheet. In this method the sheets, cut straight from the machine or "waterleaf," are placed by hand between two travelling continuous felts, which carry them slowly through a long vat filled with size heated by a steam-coil to a temperature of about 115°. On delivery at the other end the paper is laid for about twelve hours in piles, to allow the size thoroughly to saturate the paper. The sheets are next hung up on the tribbles in slips of three or four sheets in steam-heated lofts to dry, at a temperature of from 80° to 120°. After about ten hours the lofts are opened to a free current of cold air; the paper is allowed thus to "weather" for two or three hours, which gives toughness to the sheet and prevents brittleness. This is, however, a lengthy and expensive process, and only available for special classes. For the generality of tub-sized papers the paper is passed through the size in the reel. An ordinary tub-sizing vat (Plate 6) consists of a shallow rectangular box or trough heated underneath by steam. This is filled with size, in which revolve four or five wooden rollers. The web of paper passes under and over these rollers and then between a pair of brass squeezing-rolls which remove the superfluous size. It has been found by direct experiment that 100 lbs. of unsized paper will absorb from 6 to 11 lbs. of gelatine, depending on the thinness of the paper. There cannot be a stronger evidence of the necessity for the stuff being well prepared, in order to obtain a sound paper, than the process of sizing. If the pulp has been slowly prepared, so as to hold a good deal of water, it will also hold and retain the size in a manner corresponding thereto; whereas quickly-prepared stuff, which has been cut rather than drawn out in the engines, not only requires a much stronger size but is sized with much greater difficulty.

The web is now dried over a long series of open skeleton drums about 4 feet in diameter, inside which revolve fans for creating a circulation of hot air. Rows of steam-pipes underneath the line of drums furnish the heat for drying. Quick and rapid drying is not only injurious to the quality of the paper, but also renders the sizing properties of the gelatine less effectual; the number of these drums is therefore very great, as many as sixty to ninety, to ensure the process being slow and gradual. The chief drawback to this form of drying is the tension again produced on the web of paper, thus prevented from contracting lengthways, after the expansion due to immersion in the size, and which tends to impair the strength and elasticity of the fibres. An ingenious process has been invented to obviate this difficulty, but it has not yet been brought into general practice. The paper, after passing through the ordinary sizing-trough and squeezing-rolls, is carried upwards on to an elevated platform, consisting of two parallel beams which can be extended to any length desired. Two endless chains travel along these beams at a low speed. A wooden hopper at the receiving-end of the machine is filled with a number of wooden spars which are picked up at regular intervals by catches fixed on to an endless belt or chain. This chain carries and delivers the spars on to the two travelling chains on the platform. The web of paper is passed over a roller, after leaving the reel, and is allowed to fall down in a festoon or loop below. The upward travelling-spar catches the web and, on its arrival at the top, is deposited with it on the two continuous chains. At regular intervals the spars travelling upwards catch the web again so as to form a succession of travelling loops or festooons. At the other end the paper is wound up on an ordinary reeling machine, the spars falling down a slide into another hopper, where they are collected and taken back to the receiving-end. The heat is provided, as with the drums, by rows of steam-pipes extending the whole length of the machine on the floor underneath, the hot air rising and circulating about the paper. These two forms of drying machines are shown on Plate 7.

The process of sizing above described, although superior to any other method, entails a large addition of plant, labour and time to the general economy of the mill; and it was therefore only natural that paper-makers should endeavour to discover a process by which the paper could be produced sized off the end of the making-machine without the necessity of any additional process. The natural bent of their investigations was to find out some material, which when mixed with the pulp in the engine would so envelop the fibres as to render them thoroughly impermeable. The result has been the process known as "engine-sizing." There are many recipes for making this size; they are, however, almost all substantially the same in principle, the base of the size being resin. It is obtained by adding a solution of alum to a resinous soap dissolved in soda. The resulting compounds are sulphate of soda and a resinous alumina which is the size.

The following is a recipe for a size, which renders the paper thoroughly non-absorbent: Take 85 lbs. of refined soda ash 57 per cent., dissolve in about 60 gallons of boiling water in a tank fitted with a steam pipe; add gradually 6 cwt. of finely ground resin to the solution, and boil the whole gently for three or four hours. Strain the mixture through a search into tubs to cool. When cool the size separates into two substances; one, the soap of resin, soft and of a light yellow colour, the other, a dark brown alkaline liquid, which rises to the top and contains the surplus soda used in dissolving the resin. The latter should be taken off, if left it injures the quality of the size. To prepare this resinous soap for the engine it is diluted with water to twelve or thirteen times its volume, producing a milk-white solution. To precipitate the size from this solution it must be mixed in the engine with an equal quantity of a solution of sulphate of alumina or alum, dissolved to a specific gravity of 1·35 (7° Twaddell). The above quantities will produce sufficient to thoroughly size 20,000 lbs. of paper. Some makers prefer to mix the starch for stiffening the paper with the size before putting it into the engine, on the ground that it improves the size and renders its precipitation more uniform.

Engine-size renders the paper fully as non-absorbent as animal-size. The latter penetrates the sheet only slightly and forms a coating or skin on each surface, whereas the engine-size surrounds each fibre and impregnates the whole mass. Surface-sizing, however, produces a stronger, firmer sheet, and is smoother for the pen to travel over; the manufacturer also gets the benefit in the price of the paper of the additional weight of the size, amounting to 7 per cent. on the average. On the other hand, as the animal-size is mostly a skin on the surface, if the coating be broken anywhere, by the use of a knife in scratching out, the paper will only imperfectly resist ink in the place, a great disadvantage for account- and office-books and ledgers. Engine-sized paper is much cheaper to produce than animal-sized, and is therefore used principally for the lower qualities of writings, and for almost all kinds of printings where firmness and smoothness are not so much a desideratum. Most tub-sized papers have a certain portion of engine-size mixed with the pulp. This not only ensures the thorough sizing of the sheet, but also is a measure of economy in reducing the absorbing power of the paper for the animal size. Papers for ledgers and office-work are best given an extra proportion of engine-size to ensure their ink-resisting properties, and they are also sized by hand in animal-size and loft-dried.

The following rough estimate of the comparative cost in materials and wages of engine-sizing and animal-sizing paper, may be of interest.

	£.	s.	d.	
Engine-sizing, per 20,000 lbs.				
Materials	5	2	0	
Wages	0	12	6	
Total	5	14	6	Cost per lb. = 0·068 *d.*
Animal-sizing, per 20,000 lbs.				
Materials	36	0	0	
Wages	4	10	0	
Total	40	10	0	Cost per lb. = 0·486 *d.*

All the better classes of papers require smoothing or flattening on coming from the drying-cylinders of the sizing or making-machines; and a good many, especially papers for writing purposes, are wanted with a more or less high glaze on their surface. This surfacing or glazing can be done in two ways; either by hand in single sheets between a pair of rolls, or in the web through a series or stack of rolls running one upon another in an upright frame.

The hand-glazing process is adopted only for the best grades of writing-papers, as it gives a smoother, higher, and more permanent gloss than has yet been imitated by the roll-calender. In this method each sheet is placed by hand between two zinc plates, until a pile of sheets and plates has been formed sufficient to make a handful for subjecting to the glazing-rolls. This handful, of about 2 quires or 48 sheets of paper, is then passed backwards and forwards between two chilled-iron rolls gearing together. A considerable pressure can be brought to bear upon the top roll by levers and weights, or by a pair of screws. The pressure on the rolls, and the number of times the handful is passed through, is varied according to the amount of gloss required on the paper. For a mere smoothing or flattening out, specially made glazed mill-boards are substituted for the zinc plates. The hand process is an expensive and laborious one, and, where adopted, necessitates a large increase of plant and wages in the mill. A paper-mill glazing 3,250,000 lbs. of paper in a year, requires seventeen hand-machines to do the work; and the cost of this in repairs and wages amounts to fully 0·32*d.* per lb. of paper turned out.

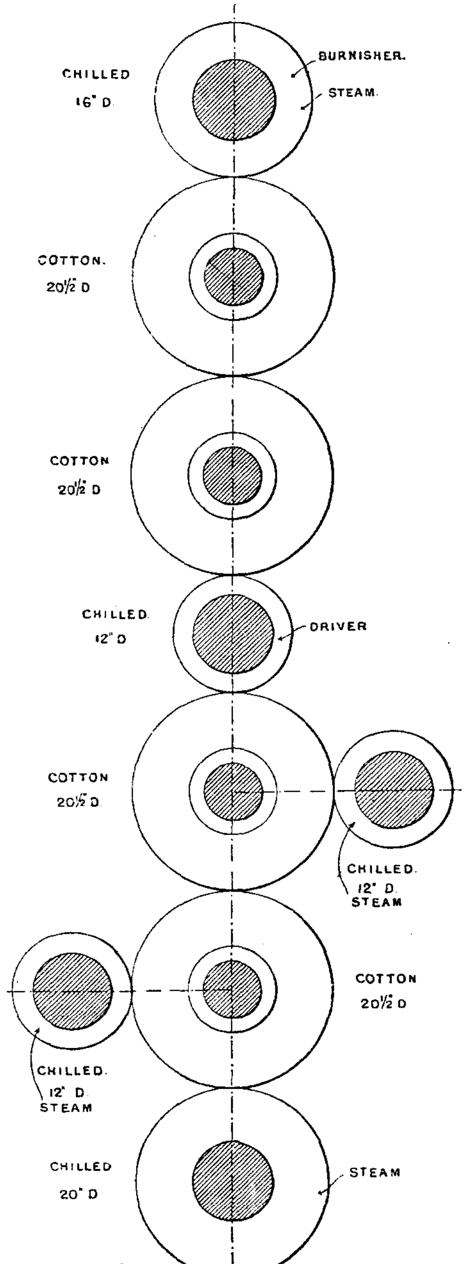
For lower surfaces and cheaper qualities the roll-calender affords a much more expeditious and inexpensive method. The paper in the web is passed in at the top of the calender and taken down through the whole stack, getting as many "nips" but one as there are rolls, and is reeled up again at the bottom. By a suitable arrangement of weights and levers a heavy pressure can be brought to bear on the rolls. As to the material of which the rolls are composed, a great deal depends upon the kind of surface, and the quality of paper to be glazed. The calender usually consists of a stack of chilled cast-iron rolls; or else, alternating rolls of chilled iron and compressed cotton or paper, so that the web at each nip is between cotton and iron. For very low surfaces a couple of nips between two cotton rolls are sufficient, producing the same style of surface as that for which the glazed mill-boards are used in the hand-glazing machines. Engine-sized papers, especially those made entirely from esparto grass, are extremely difficult to glaze, the heaviest pressure that can be applied to the rolls only producing a very indifferent gloss, besides crushing the paper and destroying its "feel" or "handle." For these papers, then, a different principle is adopted. The machines are provided with two stacks of about five or six rolls each, all of chilled iron. The web of paper is brought off the drying-cylinders slightly moist, and is passed through these calenders. To assist the surface, a pair of rolls known as "smoothing-rolls" is interposed, on machines for making engine-sized papers, halfway between the drying cylinders (Plate 7), where the paper is in a very damp state, and which imparts at once considerable smoothness to the surface. Provision is made for admitting steam to the interior of the rolls, as heat assists the glazing and helps to dry the paper at the same time. The surface produced by this method is, however, an inferior one compared to that produced by pressure. A stack of chilled rolls is not suitable for a heavy pressure; the material being unyielding, crushes the paper so entirely as to take away its character, and the web is liable to form into creases before the rolls, which not only damage the paper but tend to leave a permanent mark on the rolls themselves.

For calendered surfaces on animal-sized papers it is better to use a stack composed of cotton and chilled rolls. A heavy pressure can be applied, producing a finer and closer surface; the web is not so liable to run into creases, and if it does, causes no permanent harm to the rolls; a hard and soft surface being in contact, the hard surface seems to restore and renew the soft; and although the softer surface is easily marked by anything passing over it, the blemish is obliterated again by pressure against the harder iron surface. Fig. 6 (p. 298) is a sketch of an excellent arrangement of the rolls in such a calender, which will surface paper at the rate of 300 lineal feet of web per minute.

The glaze produced by the web-calender, is never, however, equal for gloss and smoothness to that obtained by the hand-glazing process between zinc plates, presumably due to the greater softness of the material, and closeness of the surface of zinc to that of iron. An attempt has been made to produce this in a calender by rolls covered with a zinc shell; and the Author has seen a good imitation of a hand-glazed surface by this means, but it has not yet been brought to a state of practical perfection.

A very high surface can be quickly given to paper by friction with the assistance of heat. The process is known as "burnishing," and is used mostly for envelope papers and some classes of wrappings, where one surface only of the web is re-

Fig. 6.


BURNISHER.
STEAM.
CHILLED
16" D.
COTTON.
20½" D
COTTON
20½" D
CHILLED.
12" D
DRIVER
COTTON
20½" D
CHILLED.
12" D.
STEAM
COTTON
20½" D
CHILLED.
12" D.
STEAM
CHILLED
20" D
STEAM
SCALE 1/20"

quired to be glazed. It is produced by a chilled-iron roll on one of cotton or paper, the ratio of the revolutions being as 4 : 5 or $\frac{1}{5}$ friction. Steam is admitted to the burnishing-iron roll. The highest pressure exerted on the web of paper as it passes between the rolls to produce a very high gloss, both in hand- and calender-glazing, amounts to from $\frac{3}{4}$ to 1 ton per inch width of web.

The cutting of the web into sheets is effected by two kinds of machines, known as the single-sheet cutter and the revolving cutter. The latter consists of a revolving knife, capable of cutting the full length of the web at one stroke. The number of revolutions of this knife is adjustable, so as to cut the sheet to any required length. Before coming to the revolving knife, the web passes under a number of circular knives or slitters revolving on a shaft parallel to the large knife. The position of these slitters can be adjusted on the shaft, so as to cut the web crosswise into the number of sheets required, and at the same time to remove the rough edges formed by the deckels. A travelling continuous felt carries the sheets from the cutter to a table, where they are laid in piles. A number of reels are cut at one time on this machine, all passing under the knives together. For cutting papers with great accuracy, such as water-marked papers, where the impression must appear exactly in the same position in each sheet, every web must be dealt with separately sheet by sheet. The web is carried from the reel over a large oscillating drum. During the forward motion of this drum the paper, which is kept close to it by a pair of rollers, is brought up to the knife. By a suitable mechanical arrangement a bridge clamps the sheet, and the knife cuts it; while the drum travels back again for another sheet. The amount of travel of the drum is regulated to produce a sheet of the desired length, and a boy, by noticing where the water-mark appears when the sheet is being cut, can, by regulating the travel of the drum, correct any variation in its position.

All that now remains to be done before taking the paper to market, is overhauling. This consists in sorting out all speckled, spotted, or damaged sheets, or sheets of different shades of colour. This entails considerable time and expense, as each sheet separately has to pass in review before the eye of the operative. It is, however, a process which can hardly be simplified. On going over a paper-mill manufacturing high-class papers, and seeing the enormous staff of operatives engaged in this work, and the attention that has to be bestowed upon it, the absolute necessity of care in the making department, to produce paper as clean and as regular in shade and quality as possible, will be fully appreciated.

3. *Remarks on the Economy of a Paper-mill.*—The great bulk of the power required in a paper-mill is consumed in driving the engines for reducing the raw material into pulp. A pair of engines, capable of turning out about 250 lbs. of paper daily, will exert about 40 HP. on an average; but of course this amount will vary considerably in different mills with the nature of the material used, and the mode of treatment.

The total HP. consumed in motive-power in a paper-mill for all purposes may be estimated roughly at 300 HP. per 1,000 tons of paper per annum for an engine-sized mill; and 380 HP. for the same amount for a tub-sized mill. About 75 per cent. of this power, on an average, is consumed in driving the pulping engines.

As regards the primary motive-power to be employed in driving the mill, a paper-maker will naturally prefer water to steam. The water available may, however, only be sufficient to supply part of the power required, or it may fail during the drier seasons of the year; so that steam-power has generally to be provided equal to the water-power used, as a reserve in case of emergencies.

Water-power can be utilized in two ways through the medium of waterwheels, or else of turbines. The latter have proved in every way superior to waterwheels, especially for the transmission of high powers and quick speeds. They give a greater efficiency than waterwheels, are more easily housed, and for the production of high speeds, as they revolve at a very rapid rate, do away with the multiplication of heavy gearing necessary to change a low speed to a high one.

The best mode of transmitting power to the engines, whether by toothed gearing or by belting, will depend greatly upon the arrangement of the mill. In transmitting high powers, which have to be suddenly applied, belts as a rule are not so efficacious as toothed gearing in producing a constant velocity-ratio, owing to their liability to stretch and slip, irrespective of the extra expense entailed by the heavy wear and tear. But in the reduction of raw material to pulp, especially in the beating-engine, absolute regularity in the transmission of power is not so essential as the smooth and steady bearing of the roll on the plate. There is always a certain amount of jar and vibration in the motion produced through the direct action of toothed wheels, which is entirely overcome by the use of belts; besides, the tension of the belt over the pulleys produces a steady downward bearing of the roll on the plate, which is not the case with gearing. Toothed-gearing will answer best for the transmission of the motive power in bulk to the driving-shaft; but for the production of a uniformly divided pulp, it should be subdivided to the engines through the medium of belting.

In a large paper-mill driven entirely by steam-power, only about one-half of the coal used in raising steam is consumed in the driving-power, the other half being employed in the manufacturing departments for boiling, heating and drying purposes. Where water-power is adopted wholly or in part, by far the larger portion of coal is consumed in producing steam for the manufacture pure and simple; and it is here where economy should be directed as far as possible in the saving of coal. From 4 to 6 or 7 lbs. of coal are required to produce 1 lb. of paper, in a mill employing steam-power alone, depending on the class of mill.

In connection with the above, the following considerations will arise:—whether the greatest economy will be effected by the use of condensing-engines for the main-driving, and the production of separate steam for manufacturing purposes and the low-pressure workings; or by the use of non-condensing engines, and employing the exhaust steam from these as back-pressure steam for the use of the mill. By the adoption of a condensing-engine a considerable increase of power is obtained, without extra expenditure of fuel, by utilizing the full-pressure of the steam. But in a paper-mill, where so much heat is required for drying and heating purposes, it becomes of importance not only to utilize the full pressure of the steam produced, but the total amount of heat contained in it. Now by far the greater portion of heat in steam of any temperature and pressure is present in the form of latent heat, which is not given out until it is condensed. This latent heat amounts to 537 thermal units, and is the quantity of heat required to convert 1 lb. of water at boiling point to steam at the same temperature. A comparatively small amount of heat is necessary to raise the steam to a higher temperature and pressure.

Hence, almost the whole amount of heat present in the steam used in driving a condensing-engine is wasted; and the result resolves itself into the practical question as to whether the greatest economy in expenditure of fuel is obtained by the separate production of the steam for drying and heating purposes, or by working with a non-condensing-engine and using the exhaust steam for manufacturing purposes. In a well-conducted mill, whichever plan is adopted, all waste steam is utilized in heating the water for the boilers, &c.

As it is of the greatest importance that the paper-machine should be maintained at a uniformly steady and unvarying rate of speed, to ensure regularity in the weight and thickness of the paper, it is not only convenient but necessary that each machine should have a motive-power of its own, at the same time driving the stuff-chest and pumps. The steam-engines used for this purpose should be strong, well-built, and provided with a large fly-wheel and a good quick-acting governor, to reduce to a minimum all variations of speed. The drying-cylinders of the making-machine form an efficient and convenient condenser for the driving-engine, but it is questionable whether it is not better to provide a steam-engine with a separate condenser, and to lose the heat that escapes with the condensed steam. The heat of the drying-cylinders has frequently to be increased or diminished to suit the requirements of the paper, and this alteration in the condensing power of the engine would be detrimental to a uniform and regular rate of speed. The advisability of allowing the steam to pass from one drying-cylinder to another, in place of providing a separate steam-pipe to each, has already been mentioned. The full amount of heat contained in the condensing steam will be utilized, when the number of cylinders is such that all the steam can be condensed in them.[1]

Made at first entirely from the waste products of textile manufactories and clothing, the production of paper has now far exceeded the possible supply of these materials, and other fibrous products of the vegetable kingdom have been brought in to supply the want. Esparto, straw and wood are the three most important of these, but even their supply is not sufficient for the ever-increasing demand, and great efforts are now being made in different parts of the world to discover natural products which shall yield, with profit and success, material suitable for the manufacture of paper.

A great impetus has lately been given to the trade in wood-pulp, through the discovery of one or two processes for obtaining the pure fibre from wood cheaply and satisfactorily, and some large factories have recently been established in Sweden and other places, where the supply of wood is ready at hand. India is the home of a variety of fibrous plants, and experiments have been set on foot there to ascertain if any can be made available as a raw material. To encourage these experiments, the Indian Govern-

[1] "Appareils servant à la Fabrication du Papier," § 5, Sécherie. By M. L. Vigreux of Vienna. Paris, 1881.

ment has offered a reward to the inventor of a process which will economically and profitably produce the desired result.

The total number of paper-mills in existence is three thousand nine hundred and eighty-five, producing annually 1,055,000 tons of paper made from all classes of materials. Ninety thousand men, and twice that number of women and children are employed.[1] The capital embarked in the industry exceeds £62,000,000 sterling.

The consumption of this enormous quantity of paper, is divided in the following manner :—

	Per Annum. Million lbs.
Daily papers	490
Weekly, Monthly, &c.	380
Books	150
Printing	1,020
Schools	190
Public offices	160
Letters	220
Account-books, &c.	120
Wall-paper	450
Papier-maché, &c.	205
Total	2,365

Wheels for railway-wagons are now made of compressed paper instead of iron. The dome of the new Palais de Justice at Brussels is all of paper. Flour barrels are made of it in the United States, one factory at Iowa turning out 1,600 barrels daily, from 5 tons of paper, each barrel taking 6 lbs.

In conclusion, the Author wishes to express his thanks to Mr. F. Logie Pirie, of the firm of Messrs. Alexander Pirie and Sons, for valuable advice in the preparation of this Paper.

The communication is accompanied by numerous drawings and diagrams, from which Plates 6 and 7, and the figures in the text, have been prepared.

[1] "Mulhall's Dictionary of Statistics," by M. G. Mulhall, F.S.S. London, 1884.

[APPENDIX.

APPENDIX.

TABLE SHOWING LOSSES on RAW MATERIAL DURING the VARIOUS OPERATIONS.

The percentage of free moisture in rags varies from 3 per cent. to 6 per cent.

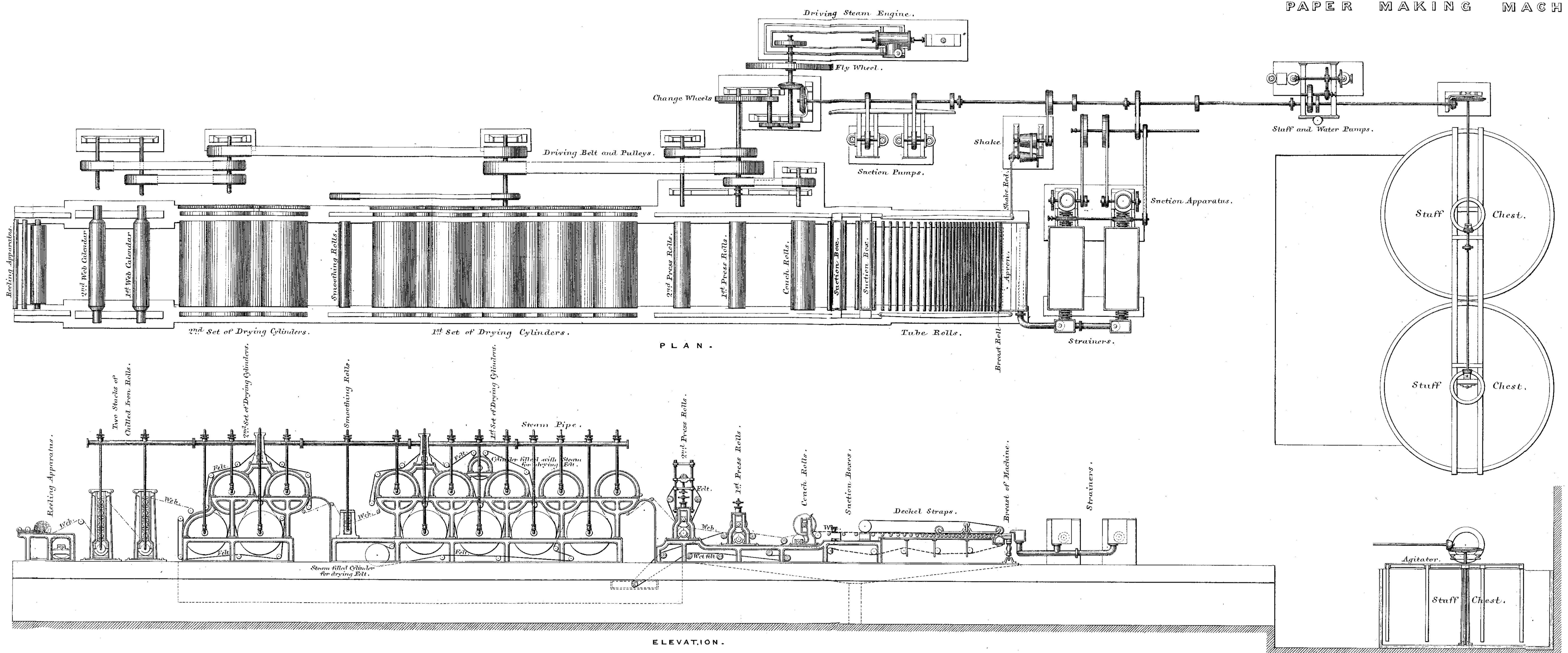
Rags.	Moisture.	Sorting.	Cutting.	Boiling.	Breaking and Bleaching.	Total.	Grand Total.	Cost Price per cwt.			Actual Cost for Waste.		
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	£.	s.	d.	£.	s.	d.
English New Pieces	3	0·5	1·0	3·0	12·5	15·15	18·91	1	5	0	1	10	9
French ,,	3	0·5	1·2	7·3	13·2	19·60	23·33	1	4	0	1	11	3
German ,,	3	0·5	1·2	11·8	11·6	22·03	25·64	1	3	0	1	10	11
No. 1 Cotton . .	3	0·9	2·0	3·0	12·4	15·04	19·96	1	1	0	1	6	3
No. 2 ,, . .	4	1·2	2·5	7·94	14·8	21·60	27·49	0	17	0	1	3	5
No. 3 ,, . .	4	1·5	3·8	11·16	13·6	23·26	30·16	0	15	0	1	1	5
No. 4 ,, . .	5	2·0	4·0	14·3	17·4	29·27	36·76	0	10	0	0	15	9
New Soft Tabs .	4	0·5	1·0	3·0	8·4	11·14	15·96	1	5	0	1	9	9
Best White Tabs.	4	1·0	4·0	8·6	16·6	23·78	30·45	1	2	6	1	12	4
Grey Tabs . .	4	0·8	2·5	15·1	9·8	23·46	28·92	0	19	0	1	6	8
Unbleached Cotton	4	0·8	2·0	12·28	13·4	24·05	29·11	0	19	0	1	6	9
White Moleskins.	4	0·8	2·0	11·00	8·9	18·99	24·38	0	19	0	1	5	1
Drab ,, .	4	1·0	2·0	13·00	10·1	21·79	27·15	0	15	0	1	0	7
Jean Cuttings .	4	1·0	2·0	17·4	6·1	22·48	27·79	0	16	0	1	2	2
Green Cords . .	5	1·0	2·5	21·3	8·0	27·64	33·60	0	11	0	0	16	6
Old Blue Cotton.	5	1·5	3·8	14·4	9·2	22·32	30·06	0	13	0	0	18	7
Shirtings . . .	4	0·5	2·6	11·6	12·4	22·59	27·98	0	15	6	1	1	6
S.P.F.F.F. Linen.	4	0·8	2·0	8·5	11·8	19·38	24·74	1	5	0	1	13	2
S.P.F.F. ,, .	5	1·3	2·4	11·1	12·8	22·51	29·08	1	0	0	1	8	2
S.P.F. ,, .	6	1·8	2·7	17·36	19·6	33·62	40·37	0	16	6	1	7	8
No. 1 Linen . .	4	0·5	2·0	6·8	7·4	13·77	19·28	1	4	0	1	9	8
No. 2 ,, . .	5	0·8	2·4	14·5	8·2	21·54	27·83	1	0	0	1	7	8
No. 3 ,, . .	6	1·0	2·7	19·15	9·8	27·11	34·00	0	16	0	1	4	3
No. 1 Russian L.	6	1·5	2·4	18·7	10·0	26·90	33·94	0	17	0	1	5	9
No. 4 ,, .	6	3·0	5·0	30·0	20·7	44·53	51·94	0	13	0	1	7	0
Linen Duck Clippings . . .	4	0·5	2·0	15·4	9·6	23·58	28·46	1	5	0	1	14	11
Linen Threads .	4	0·5	2·0	12·5	12·6	23·55	28·43	1	5	0	1	14	11
New Blue Linen.	4	0·8	2·0	15·1	13·9	26·90	31·76	1	0	0	1	9	3
Unbleached Linen	4	0·5	2·0	19·2	16·0	32·14	36·47	0	19	0	1	9	10

Esparto.	Boiling.	Breaking and Bleaching.	Total.	Cost Price per Ton.			Actual Cost for Waste per Ton.			Remarks.
	Per cent.	Per cent.	Per cent.	£.	s.	d.	£.	s.	d.	Lbs. Per cwt.
Spanish . . .	39·24	11·00	45·92	8	7	6	15	10	2	15·2 Caustic soda 9 Bleaching powder
African . . .	46·00	17·18	55·27	7	0	0	15	13	2	20 Caustic soda 9 Bleaching powder

PAPER MAKING MACHINERY.

THOS KELL & SON, LITH 40, KING St COVENT GARDEN.

PAPER MAKING MACHINERY.

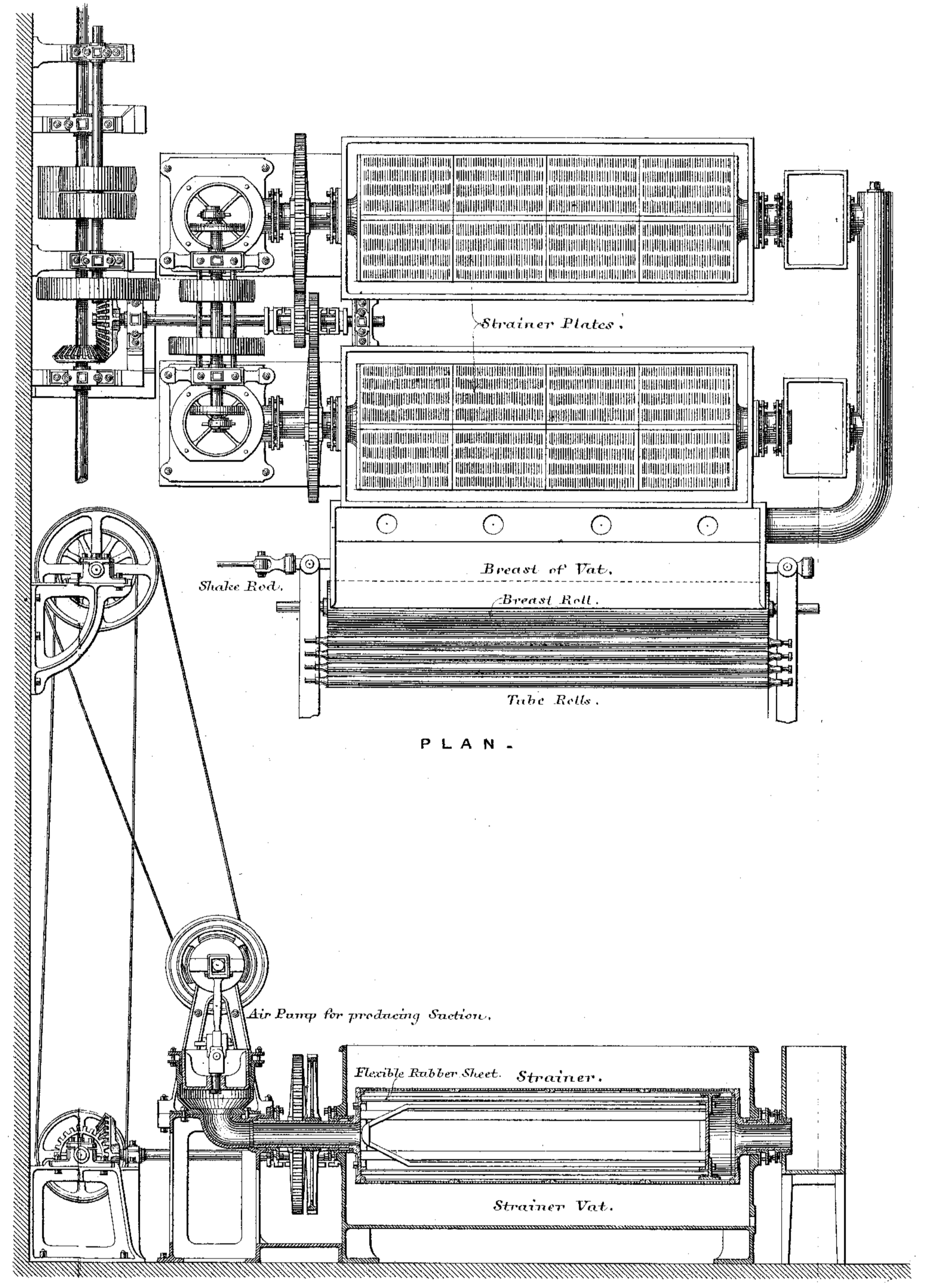


ELEVATION.

96 INCH PAPER MAKING MACHINE, FOR FINE WRITINGS AND PRINTINGS.

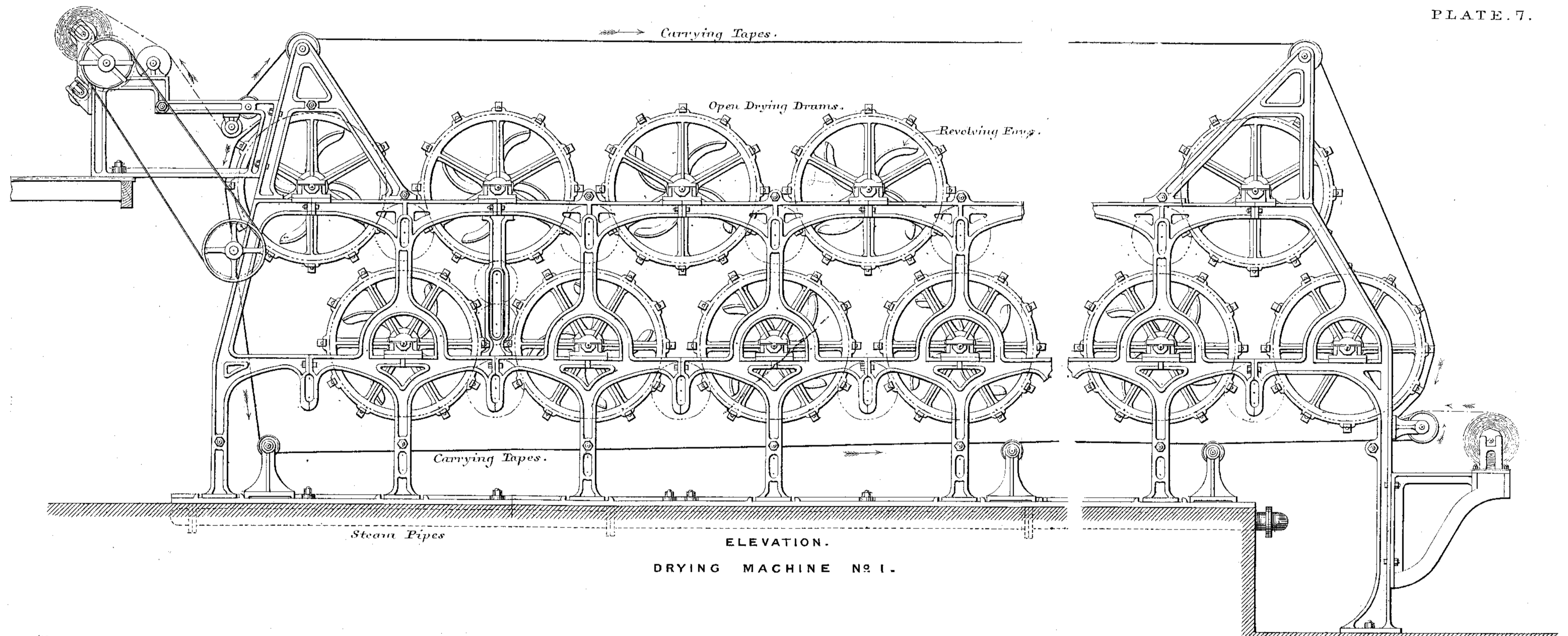
J. W. WYATT, DEL.

Scale: 1/8 Inch = 1 Foot.



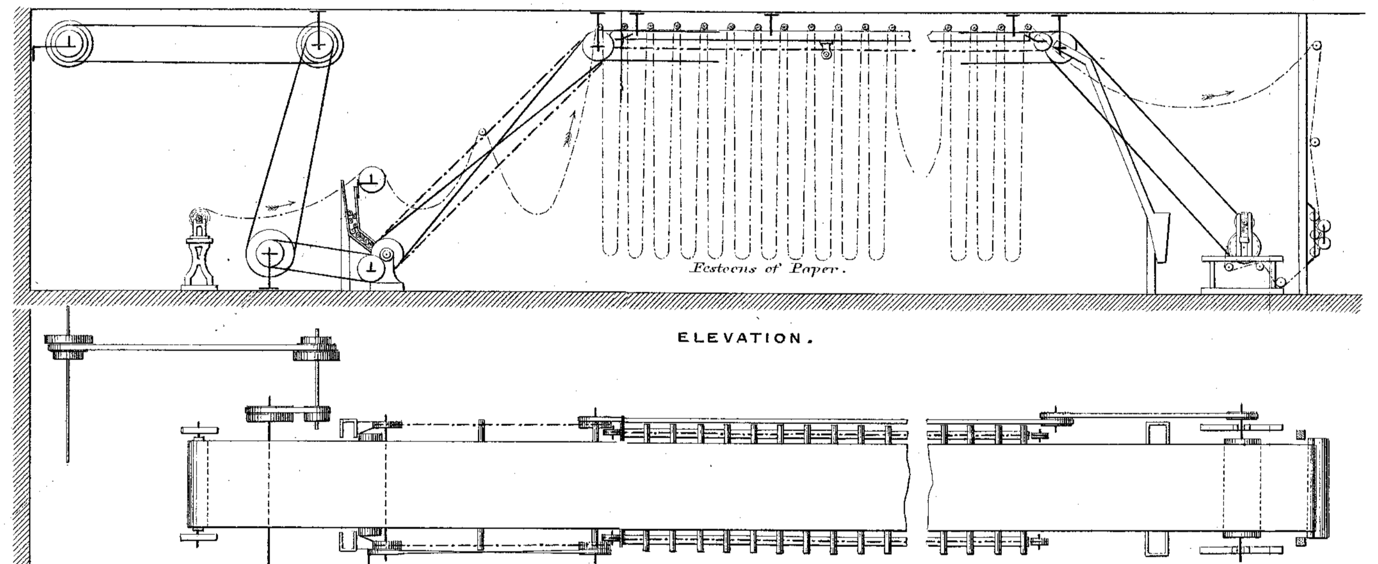
SECTIONAL ELEVATION.

REVOLVING STRAINER, FITTED WITH BERTRAM'S SUCTION APPARATUS.

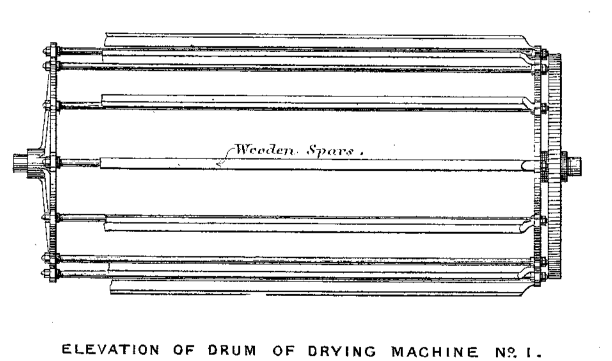


ELEVATION.

DRYING MACHINE Nº 1.



DRYING MACHINE Nº 2.



ELEVATION OF DRUM OF DRYING MACHINE Nº 1.

Scale: 1/4 Inch = 1 Foot.

Scale: 3/16 Inch = 1 Foot.

THOS KELL & SON, LITH. 40, KING ST COVENT GARDEN.