ON

INDIGO MANUFACTURE:

A PRACTICAL AND THEORETICAL GUIDE TO
THE PRODUCTION OF THE DYE:
WITH NUMEROUS ILLUSTRATIVE EXPERIMENTS.

BY

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INDIGO MANUFACTURE.

PREFACE.

This monograph deals only with the subject of Indigo manufacture, and it is hoped that it may prove of real service to persons interested in Indigo—whether proprietors or planters.

Indigo planters in India live in isolated places, for the most part miles away from each other. They generally learn the details of their business by serving a kind of apprenticeship as assistants to older hands. The ordinary routine of practice is fairly simple and easily learnt, but the true theory of indigo manufacture is very little understood, and unnecessary losses are frequently incurred in consequence; and planters have often been known to lose large sums of money through listening to the suggestions of people possessing a very little quasi-scientific knowledge.

I believe that the contents of this monograph cannot fail to be of use to the classes of persons for whom it has been written. I have, myself, mad most extensive original experimental investigation in connection with the subject-matter of my mono graph, and one distinctive feature of the worl consists of descriptions of numerous simple experi ments at the end of each chapter, to illustrate the principles enunciated in the body of the preceding chapter. These experiments are all of such a character that they can easily be repeated by any Indigo planter with the most ordinary appliances, and they should contribute materially to a better and more real understanding of the subject than could be acquired by mere enunciation of facts and theories.

J. BRIDGES LEE.

Lahore, January, 1892.

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INDIGO MANUFACTURE.

CHAPTER I.

EXTRACTION OF THE SOLUBLE MATTERS FROM THE PLANT BY WATER.

THE various steps or processes in indigo manufacture at an indigo factory may be grouped in natural sequence under three heads :—

(1) The treatment of the raw plant with the object of extracting from it the ingredients which at the next stage in manufacture will yield the indigo.

(2) The treatment of the product extracted from the plant for the purpose of obtaining from it a granular precipitate of indigo blue.

(3) The collection and subsequent treatment of the indigo blue precipitate, with the purpose of converting it into good, sound, dry merchantable cakes.

The first stage of manufacture is probably the most important, because upon the treatment of the plant itself will primarily and chiefly depend both the quantity and the quality of the dye afterwards obtainable.

As might be expected from the large extent to which the plant is grown, and the high market value of the dye, a number of different persons have at various times devoted attention to the methods of manufacture, with a hope of being able to improve on the old primitive methods, and various mechanical arrangements have been devised from time to time, which have to a certain extent assisted or superseded manual labour, but in principle the methods by which indigo is obtained from the plant to-day are essentially the same as they have been since the days of our forefathers.

In principle these methods consist:—

(1) In the extraction of soluble matters from the plant by water.

(2) In precipitation of indigo blue from the aqueous infusion by the oxidising influence of the atmosphere.

(3) In draining off the mother liquor from which the indigo blue has precipitated, and in boiling afterwards with water, straining, compressing, and drying the precipitated indigo.

In this chapter I shall treat only of the extraction of the soluble matters from the plant by water.

The old-fashioned, time-honoured method is now, and has always been, to steep the raw fresh-cut plant in large vats, at the ordinary atmospheric temperature, *i.e.*, no artificial means are used either to raise or to lower the temperature of the plant, the vats, or the water.

The common practice is first to pack the fresh-cut shrubs as closely as possible in the vat, then to spread layers of the plant horizontally, so as to make the uppermost level of the plant as nearly as possible horizontal, then to lay on the top of the plant a horizontal trellis-work of bamboos, then to compress the plant by pressure applied above the bamboo trellis-work, the pressure being exerted by means of various simple mechanical arrangements of levers or stout wooden beams; the beams pressing on the bamboo trellis-work are then pegged or otherwise fastened down to the level to which they have been depressed, and, lastly, water is allowed to flow into the vat, until the level of the water in the vat is a few inches at most above the uppermost level of the plant. After all this has been done, the whole vat is allowed to rest until the planter, relying on his personal experience, thinks the steeping has lasted long enough, when valves, communicating with the base of the vat, are opened, and the liquor is allowed to drain off. Ordinarily, the time during which the plant is allowed quietly to steep is from ten or twelve to sixteen hours or more.

Commonly the steeping commences in the afternoon of one day, and the liquor is drawn off some time in the following morning. As beforesaid, the time of steeping is determined by the planter or his assistant in charge of the factory, but the time actually required for steeping is determined, in great part, by the state of the weather, hot or cold, wet or dry, the state of the plant when it was put into the vat, and the quality of the water. The planter, besides taking general note of these circumstances, will especially observe the changing condition of the uppermost surface of the liquor in the vat, and observation of the state of the surface of the vat, and of the colour of the first portions of liquor which flow off at the bottom, afford fairly satisfactory guides to enable a practical man with experience to decide when the whole liquor in the vat should be drawn off.

The above description, with occasional modifications, represents the ordinary practical treatment of the raw plant, and, so far as I am aware, no important improvements on the general methods above described have hitherto been introduced in practice.

Many persons have tried from time to time the effect of adding various chemical substances to the steeping vat, and some few persons have perhaps imagined that by such means they have improved either the quantity or the quality of the ultimate produce, but the general consensus of opinion among practical planters of long standing would seem to be that all kinds of doctoring stuff introduced into the steeping vat are useless, or worse than useless, and there can, I think, be very little room to doubt but that this opinion is correct.

So far as the steeping vat is concerned the essential conditions for good produce are (*a*) good plant; (*b*) good water; (*c*) correct steeping. By (*a*) good plant I mean plant of a good quality raised from the seed of plant known to be rich in indigo-dye producing material.

The plant should be in good condition, and clean and unbruised; and the whole of the plant used for one steeping should have been cut at or about the same time, and be all in approximately the same condition as regards freshness; otherwise it will certainly happen that the freshest plant will be under-steeped when the stale plant commences to be over-steeped.

It does not fall within the scope of this small treatise to discuss the conditions to be observed for rearing good plant; we are only concerned in this place with a discussion of the means for obtaining the best possible results from the plant as delivered at the factory. At the same time, it is, of course, essential to bear in mind throughout that it is the plant which yields the indigo-forming material, and, except the plant contains a good supply of that material, you cannot hope to obtain a good supply of produce. Whether indigo exists ready formed in the plant, as deoxidised or white indigo, or whether it is formed ultimately from indican or from other substances, there is no doubt but that the indigo—white or other indigo-forming substance or collection of substances extracted from the plant by water is formed in the living plant by vital processes appertaining to the plant itself. A maund of the plant, when cut, has within itself a certain quantity of material freely soluble in water, which is capable of yielding, on exposure to the air, a certain number of grains of indigo. You may, by defective manipulation, fail to extract a considerable proportion of that substance, or you may extract nearly the whole; but you cannot increase the total quantity of that substance which you had to start with in the fresh cut plant. When the vital processes by which indigo forming material was formed in the plant come to an end, the manufacture of the material by the plant ceases.

Indigo, as the planter gets it in the oxidising vat, is a direct product of the oxidation of something soluble in water which existed in the living, growing plant, and is certainly not a product of subsequent fermentation.

This last-stated proposition it is important to insist upon, because there is a general, widespread belief among planters that the ultimate formation of indigo blue depends upon a process of fermentation, as it is called, in the steeping vat, and this fallacious belief has served to divert people's attention from the true theory of the steeping vat, and so to prevent the discovery of more expeditious and more cleanly methods than those in common use. I have accordingly taken some pains to set out in detail at the end of this chapter a number of simple experiments to show that fermentation is not necessary for the production of indigo blue; and I trust that any planter who will take the trouble to repeat those experiments will be able to satisfy himself, not only that no sort of fermentation is necessary to produce good indigo, but that any amount of the so-called fermentation or putrefaction which there may be during the process of manufacture, causes positive injury to the indigo product by adulterating it with filth, and considerably impedes all the later stages of manufacture.

In truth, there is no special distinctive kind of fermentation for the indigo plant, so far as I have been able to discover by careful observation and very numerous oft-repeated experiments.

The indigo plant—like nearly every other kind of green plant—will rot if left in water long enough, and while rotting it will give rise to all sorts of foul, offensive, stinking products of decomposition; and, like other rotting plants, will give off foul smelling gases, but at no stage is there any specially distinctive kind of fermentation apart from progress on the road to decomposition and decay, *i.e.*, there is no fermentation of a kind corresponding to the alcoholic, or acetic, or butyric fermentation.

In practice, of course, no one ever thinks of leaving the plant to soak in the steeping vat till it rots, but before the liquor is drawn off changes have commenced, or even sometimes progressed some distance on the road which leads to the development of those slimy products which cause so much trouble and annoyance when they appear in quantities at the later stages of the manufacture.

The general belief that there is a special fermentation process, and that the formation of the indigo is dependent upon this process, would seem to be based upon the twofold observation—first, that the liquid in the steeping vat does froth up while the steeping is going on, in the same sort of way that a beer vat would froth when fermenting; and secondly, experience has told the planters that the best time to draw off the liquor is after the escape of gas bubbles has commenced to slacken, and the frothy head has begun to subside. Planters have also learnt by experience long ago that if they were to draw off the liquor before the frothy head had formed they would get exceedingly little indigo.

These facts and observations have afforded a plausible sort of basis for the prevalent theory, but the theory is not sound, and the observed facts are capable of another explanation, and are all consistent with what I believe to be the true theory of the vat, while there are many experimental facts which distinctly negative and are inconsistent with the fermentation theory.

The true theory of the steeping vat is exceedingly simple, and is this:—

The leaves of the indigo plant, which contain by far the largest proportion of the indigo-forming materials, are covered with multitudinous tiny hairs, very close together.

These hairs entangle air in their interspaces, and when the plant is first flooded with water the leaves do not get wetted, except at their edges, or where by chance they may have been roughly handled or bruised, and every leaf will have over nearly the whole of its surface a protecting film of air which serves effectually for a time to hold off the liquid. The stems and branches and cut surfaces of the plant are not similarly protected, and they are wetted immediately, or almost immediately, by the circumambient water, which they absorb in moderate quantities, as the water has less density than the plant-juices. This absorption of water causes the plants to swell, and a certain small amount of movement among the immersed plants, and greatly increased pressure in every direction between adjacent parts of plants, the liquid absorbed by the stems and branches travelling, of course, also to the leaves and causing them to swell also. These slight internal movements of the solid and liquid contents of the vat, and especially the pressure and occasional sliding motion of leaves in contact, will result in driving out some of the air in the shape of bubbles, so that a mild kind of bubbling will commence early in the steeping process, but the actions already described will not by themselves suffice to lay bare the greater part of the leaf surfaces to the action of the water.

This result will only be achieved when the action of small living organisms comes into play on a large scale, as it will after some hours. No matter how fresh the plant when first packed in the vat, or how fresh and clear and sweet the water when first let on, the liquid after a variable number of hours will be found to teem with microscopic animalcules, in a state of the liveliest activity, and these myriads of minute organisms will rapidly lay bare all the leaf surfaces within their reach, by attacking and eating the hairs and by keeping up a state of violent molecular activity throughout the whole mass of the liquid, so that the previously entangled air will now rapidly escape in bubbles of gas, which will force their way to the surface and make the froth-head appearance so well known.

When the frothy head begins to subside, then it may be known that nearly all the leaves have come in contact with the surrounding fluid. The indigo forming substance is very freely soluble in water, and the leaves are so thin that contact with the water on both sides for an exceedingly short space of time suffices to extract all their soluble juices, and it is time to draw off the liquor. Nothing can be gained by waiting longer. Some small proportion of the leaves are probably still not wetted, but most will be, and, meanwhile, the oxygen of the air will have already commenced to precipitate appreciable quantities of indigo blue near the surface of the vat, all of which will be lost to the planter, as it will not find its way down through the plant to the oxidising vat. Also the animalcules, before referred to, will go on multiplying at a prodigiously rapid pace, and their living and dead bodies and their ejections and the *débris* which they have succeeded in detaching from the surfaces of the plants, will all contribute to make the liquid more or less milky or slimy, and to spoil the ultimate quality of the indigo, and impede the subsequent operations of settling and pressing and drying.

In accordance with the above-stated theory of the steeping vat, it will be seen that the planter's first need in dealing with the raw plant is, after he has obtained good water to wet it, to proceed to get it wetted. The ordinary method of steeping is a lengthy process at best, and is open to the objection above pointed out.

Obviously, if my theory is sound, it would be well, if possible, to dispense with the animalcules altogether, and also to avoid disintegrating the plant; and if the operation of extraction could be quickly performed there would be a great saving from every point of view, and a purer product. These results I have achieved by the simple process of applying heat to the bottom of the vat after it has been packed with plant and flooded with cold water as usual. I begin to heat the vat below immediately the vat is charged, and in my experiments I have found from one hour to one hour and a half sufficient time for the process of extraction, prior to draining off the liquor to the oxidising vat.

An ordinary fire under proper control, or steam pipes, or hot water pipes will do to heat the vats.

I do not ordinarily raise the mean temperature of the vat contents above 150° F., as I find that by the time that temperature is reached all, or nearly all, the air bubbles have been cleared out, and subsequent inspection of the plant has shown that it was all thoroughly moistened. Also I have found that the produce of indigotin is larger with this method of extraction than with the ordinary cold steeping method.

The effect of heating the vat from below is, of course, to cause convection currents, which sweep past and over the surfaces of the leaves, and so help to sweep away the air. Also the heat expands the air, and so aids its escape; also, I think it probable that the warm liquid acting on the hairs softens them, and so enables the air to be more easily swept away.

My method certainly does not engender fermentation of the vat contents before the liquid is drawn off, and it yields a clear, bright fluid, free from all suggestion of muddiness or sliminess.

This method of extraction, as my readers will observe, is new.

While treating of the steeping vat, and before going on to consider the subject of water supply, to which the next chapter will be devoted, it may be as well to point out that the old-fashioned method of compressing the plant in the vat is clumsy and unscientific, and results in loss of indigo, besides occasionally causing loss to the planter in other ways.

Indigo plant before steeping is of less density than water, and it is obviously necessary to use artificial means to keep it down, otherwise a large quantity of the plant would be floated up above the water surface, and the idea of pressing and fixing it down very naturally suggested itself to the earliest pioneers in indigo manufacture.

Also if the plant is pressed down very tight a relatively smaller volume of water is required for a given weight of plant than if the plant were loosely packed and lightly held down; and, accordingly, with close packing and tight pressure, it may be expected, as will, in fact, be the case, that the liquor to be dealt with in the oxidising vat will contain a larger percentage of the indigo-producing material than in the case of loosely packed and slightly compressed plant.

On the other hand, if plant is too tightly compressed, there may be increased obstacles to the water getting at all parts of the plant in the vat ; it may be difficult for the air bubbles to find escape towards the surface.

These advantages and corresponding disadvantages of pressure would apply to any kind of pressure, however applied, but the existing method of fixing down the plant to a definite horizontal level, by a rigid arrangement of levers and pegs, is open to much more serious objections, which have only to be stated to be understood.

In the first place, the pressure originally applied to the freshly packed plant, bears no sort of ratio to the pressure which will be exerted upon the plant after the water is let on and during the subsequent stages of steeping.

Plant which has been only moderately compressed at the outset may, during the process of steeping, and while the stems are swelling with absorbed water, develop a pressure so great as even to break the beams or rend the solid masonry to which these are connected. Such excessive pressure at this stage serves no useful purpose whatever, and may occasion damage to the planters.

Also when most of the entangled air has escaped from the vat, and after all or most of the leaves have got wetted, and their soluble contents dissolved out, nearly so great as might be imagined by anyone who has not gone into the matter experimentally. Strictly speaking, if your plant has been well and closely packed, comparatively very little pressure per square inch will be required to keep it down below the level of the water, provided that at the initial flooding the water level has been raised to a height of some few inches above the uppermost level of the plant. The buoyancy of the plant is at no time anything remarkable, from start to finish. The chief cause of the buoyancy at first is the entangled air, which, as previously explained, forms a film over the surface of every leaf; and if warmth is applied to the vat, the expansion of this air by heat will tend to increase the buoyancy, until such time as the air has detached itself from the plant and gone off as bubbles. This process of detachment of air-bubbles is a process which goes on during the whole period of the steeping, and the remaining plant gets less and less buoyant the more air has escaped, till at last it has little or no buoyancy left. To overcome the mere buoyancy no very enormous pressure is therefore required, but besides buoyancy proper, there is the other pressure previously referred to, which is of quite a different nature, and which is generally amply sufficient under existing, old-fashioned arrangements to make the beams crack, and sometimes even to break materials which would not yield except to a force of many tons.

This kind of pressure is due to a swelling out of the substance of the plant itself as it absorbs liquid, and as is the case with the other molecular forces, the pressure originated from this cause may be prodigiously great, but it will operate only through very short distances.

This kind of pressure is the same kind of pressure as is exerted by roots which have worked their way into cracks in masonry, and which finally, as they expand in growing, rend open the masonry.

To attempt to counteract by artificial mechanical means the force of the expansion of the plant as it swells with absorbed moisture, is to attempt something which it is hopeless to think of accomplishing on a large scale, and if you could succeed you would have gained nothing practically. In practice, the height to which the upper level of the plant will be raised in consequence of the swelling out of the plant structures will be very small, less, indeed, with indigo than with many other common plants, and in the deepest vats in ordinary use the rise of level from this cause will never exceed a few inches.

A fixed dead weight, such as I would use, can yield to this pressure, and rise a few inches without any harm being done, but it will not yield to any tendency for the plant to float, and from the nature of the arrangement proposed, any dead weight will always exert the same pressure on the plant from the start to finish.

This use of dead weight, as described above, in place of mechanical pressure, such as has commonly been employed at factories, has been patented under the Inventions and Designs Act of 1888.

The next matter we will consider is the method of packing the plant in the vat. Some planters attach much and some comparatively little importance to this.

The matter is not really of any vital importance; it is best to pack the plant upright, as far as is conveniently possible, using horizontal layers only to fill up inequalities in the upper surface so as to make the upper surface as nearly horizontal as possible.

The advantages of an upright packing are, first and chiefly, that gas bubbles can escape much more freely from vertically packed plant than from plant horizontally packed, so that, as before explained, the plant will more quickly get wetted. Also as convection currents in liquids mostly play up and down, and as the leaves for the most part will have an approximate average vertical direction when the plant is vertically arranged, the leaves will be more easily and more quickly swept clear of air, and the internal circulation of the fluid contents of the vat will be less impeded than if the plant were horizontal.

Further, when the plant swells from absorption of moisture, the swelling will be mostly in thickness, and the stems will not elongate to any considerable extent.

With vertical packing the swelling of the plant will not, therefore, tend to any considerable extent to raise the plant out of the liquid.

Probably the best of all possible methods of packing is to first make up all the plant into bundles of convenient sizes, every bundle to consist of one-half of the plant standing erect, and the other half upside down. By this means a close packing can be obtained, while preserving the general vertical arrangements of the stems and leaves, and with good management it ought to be possible altogether, or nearly altogether, to dispense with a horizontal layer at the top.

That horizontal layer when it is close packed, as it usually is immediately upon the leaf tops of the vertical plant, and then firmly compressed from above, is apt to oppose a considerable obstacle to the escape of gases from beneath.

I would suggest that when the fresh plant is first cut in the fields it should be immediately tied in bundles of convenient standard size, and weight, and it should be the business of some responsible servant on the spot to see these bundles made up immediately as the plant is cut.

These bundles should then be packed carefully on the carts, and on arrival of these carts at the factory should at once be transferred, without opening, to the vats in process of being filled. The man in charge at the field should have a book in which to enter the total number of bundles cut and despatched, and the man in charge of the packing of the vat should have another book in which to check off the packing. By following the course suggested the planter will be enabled to obtain fairly accurate information concerning the produce per acre of the different fields under cultivation. He will also know approximately without the trouble of having any weighments at the factory, how many maunds of plant can be packed in each vat, and he will be able to estimate roughly the efficiency of the work of cutting, carting, and packing in the vats, all matters of some importance from a pecuniary point of view; and, besides, if some little pains be taken in securing that the bundles are built up uniformly in the first instance, there should be little or no difficulty in packing the vat uniformly, and entirely with the plant stems pointing up and down, so that a dense layer of compressed leafy structure at the top will no longer be required to render the upper surface approximately horizontal.

Probably the best plan to construct the bundles will be to have all plant as it is cut transported immediately by coolies to some one place in the field, where there should be a weighing machine, similar in general construction to the machinery used for weighing luggage at railway stations, but instead of a small platform there should be a larger flat platform to the machine, the length of the platform to correspond with the length of the bundles to be made.

The bundles should be then constructed by first laying transversely on the platform a piece of common rope of the proper length, to tie the completed bundles; and then a man, whose special duty it should be to make up the bundles, should as rapidly as possible lay on the plant lengthwise in successive handfuls, having the cut ends of the stems pointing towards opposite end of the platform; and he should see that the two ends of the bundles reach, but do not to any extent overlap, the ends. So soon, then, as he has laid on sufficient plant to counterbalance the weight agreed to be taken as the standard unit, he should tie the rope round the bundle, and it should be at once transferred to a cart standing near. It is, perhaps, needless to observe that the space around the machine should be all kept as clean and free from dust and dirt as possible. Probably, in most cases a liberal spreading of clean straw will be found to be a convenient bed on which to lay fresh-cut plant before it is weighed and loaded. Every cart when it is loaded should be ticketed, the ticket to bear a serial number to show the number of bundles it contains, the weight, the field, and the time of loading, and when it starts for the factory; the time of despatch should also be noted on the ticket, and a man at the factory should note the time when the cart arrives there.

Every effort should be made to ensure that the weighment, loading, and despatch shall go on regularly, and keep pace as nearly as possible with the cutting of the plant in the field.

The order of the despatch of the carts from the field to the factory should follow the order in which they have been packed, and when the carts reach the factory they should there be drawn up in order of loading, so that the first cart loaded shall be the first unloaded, and so on, the bundles being in all cases, when this is possible, transferred direct from the carts to the vat, and when the vat has been charged, it should also be ticketed by transfer of the cart tickets of those carts which have been unloaded into the vat, and also by a separate ticket to set out the time when loading commenced, the time when finished, the total number of bundles of plant, or, what is the same, the total weight of plant in the vat, and the time the water is let on, and, ultimately, the time it is drawn off, together with any special notes, which the planter in charge may think it useful or interesting to make.

When the steeping vats are drained off, the whole block of tickets should be transferred to the oxidising vats, which should have also their own special tickets, and so on through all stages of manufacture, up to the ultimate stage of packing and despatch of the indigo chests, when the bundles of tickets may be transferred to pigeon-holes in the factory office, and kept as part of the office records for as long as is thought desirable. The vats themselves should bear consecutive numbers, and should be brought into use in regular consecutive order, no fully charged vat being kept waiting for water till the next is filled; and directly a vat is flooded with water, the process of warming up the vat should be started, and the particulars of the time, temperature, &c., carefully noted on the vat ticket. For convenience sake, the tickets representing all stages of manufacture—from the field to the packing-case—may be strung together on wire, the tickets being all provided with small brass eyelets, the uppermost ticket at any time representing the facts of the stage of the manufacture then in progress, and the tickets below representing all the past stages in regular backward order. Also, it may be convenient to employ tickets of different distinctive colour to represent the different stages, so as to facilitate easy after reference.

The system of regular, continuous, uninterrupted working, and of the preparation and of the preservation of continuous contemporaneous records in the shape of a series of tickets, will, if put into operation, be found to assist the planter very considerably in checking and supervising all stages of the manufacture. To some readers, the system proposed may appear to present practical difficulties; but most of these can be got over by a little care and determination. The time consumed in making the necessary entries on the tickets will be very little indeed; and the advantages of having an efficient check system of records are so great that it is well worth while to make a determined effort to get such a system into regular working order. One of the greatest difficulties of factory administration is the obtaining and organisation of sufficient and efficient transport during the "mahai" season; but if this department is not well organised, and bullock cart drivers and others are allowed to bring in plant at all sorts of times in an irregular, haphazard sort of way, and to deposit it more or less promiscuously in sheds, from which it is removed after irregular intervals of time to the vats, the planter will certainly be a loser in more ways than one.

For really efficient economical working, every arrangement about the factory should be co-ordinated to every other. The plant should be loaded and brought in as soon as it is cut, it should be packed in the vats and steeped as soon as it is brought in, the liquor should be drawn as soon as it is ready for drawing; it should be submitted to the oxidising process as soon as it is drawn, and so on to the end. If you cut plant in excess of what you can carry away at once, you suffer waste of material. If, when plant reaches the factory, you have no vat ready to put it in, you again suffer waste of material and labour. If you keep one vat waiting for another to be filled, you lose time, and therefore money, in the shape of a share of the daily wages of the people employed, and your plant suffers and falls off in indigo yielding capacity, and so on everywhere through every stage of manufacture, a haphazard or irregular system of working means loss on all hands as compared with a regularly co-ordinated system.

Hereafter I shall show how, with the aid of a properly co-ordinated system of working, and some improved methods at various stages, the manufacturing capabilities of any given factory may be increased at least fourfold, and often to a much greater extent, without any considerably increased tax on the factory resources, except in the matter of transport. As most existing factories are now worked, it not unfrequently happens that a period of four or five days, and occasionally even more, may elapse from the time when carts first reach the factory with plant to the time when the finished indigo product is ready for transfer to the drying house; whereas with really efficient arrangements the maximum period of time, from the arrival of the plant to the conclusion of the cake cutting, should never exceed twenty-four hours, or may even be reduced to twelve hours, with no injury, but rather benefit to the quality and quantity of the finished product in relation to the quantity of plant used.

Another matter for consideration in connection with the steeping is: what should be the depth of the vat in relation to its other dimensions? All steeping vats which I have ever seen are square, but in my opinion they are all too shallow in proportion to their other dimensions. Probably planters have found, or at least the persons who were mainly instrumental in settling the present common form of the vat, must have thought they found some practical advantages in the kind of vat adopted, and I have been informed recently by a planter that some of the most recently constructed vats in Tirhoot and Bengal have been built even more shallow than the vats hitherto used, under a belief that shallow vats yield larger produce. If this is really a prevalent belief among planters in these days, I am at present at a loss for want of statistical facts to ascertain upon what materials exactly that belief is based. Theory seems to indicate with sufficient clearness that the steeping vat should expose a very small surface to the atmosphere, and the oxidising vats a large surface.

Experiments in thin glass vessels, where the progress of operations can be watched, point clearly to the conclusion that there is always some waste of indigo from oxidation at the surface of the steeping vat before the steeping process is fully completed, and the larger the exposed upper surface the greater the waste from this cause.

The extraction of the plant by water will proceed quite satisfactorily in a bottle fitted with a cork, through which a fine glass tube, or a quill, of tooth-pick size, is passed so as to allow of the escape of gases from inside the bottle, but to allow no quantity of air to flow into the bottle. Altogether it can be proved in many different ways that free access of atmospheric air is not necessary to promote the progress of the steeping process, and it can also be demonstrated that if, on the other hand, air is blown into the steeping vat, a quantity of blue indigo will be precipitated, which will adhere to the plant when the liquor is drawn off, and so result in the loss of produce.

With my method of warming up the vat contents by artificial heat, I have not the least doubt but that the deep vats will yield better results than shallow vats in proportion to the plant used.

It is possible that where shallow vats are now used some benefit may be derived from the heating action of the sun's rays, when they reach the vat either in the evening or after sunrise.

It is a matter of general observation among planters that the steeping process is more rapidly completed when the vats are warmed by the sun's rays than when the whole process is completed in the shade.

Also the animalcules, of which I have previously spoken, are fond of light and warmth, and they will develop in greatest numbers near the surface, where, with the common method of packing and pressing, the densest layers of plants are to be found.

These causes may hasten the steeping process, and the total volume of produce may be increased by the bodies of myriads of the animalcules and fragments of disintegrated plant-tissue, while with a deep vat there would under the ordinary system be comparative stagnation in the lower parts of the vat, and the leaves, which chance to be packed at a considerable depth below the surface, might still be unwetted, even after the upper layers were completely extracted.

Hence it is possible to understand how and why shallow vats may have come into favour, if they have done so. Besides, shallow vats are more easy to pack and to empty than deep vats. They require less strength and depth of masonry. Shallow layers of plant are more easy to compress than deep layers, and will develop a smaller total of upward pressure when the plant expands, and so endanger to a less extent the compressing structure and the masonry; and a lower head of water will suffice to flood them, and therefore less pumping power will be required to be used. All these considerations are so many points in favour of the use of shallow vats under the present common every-day method of working; and if, besides, they yield as much or more produce without any considerable falling off in quality, there would seem to be sufficiently strong reasons for preferring to use them.

On the other hand, shallow vats do certainly entail the immediate loss of a certain quantity of good indigo. Anyone watching the surface of the vat just before the vat is about to be drawn, and during the drawing-off process, will see that this is a certain fact; and if the upper layers of plant are afterwards picked up by hand and examined, they will be found to have a film of insoluble blue indigo adhering to them. The loss of indigo from this cause can be shown to be directly proportioned to the extent of surface exposed to the air. Here we are face to face with a perfectly certain loss, which is, with equal certainty, due only to the action of the air over the exposed surface; and this loss can be directly avoided in proportion as the extent of exposed surface is limited. Hence, other things being equal, a vat exposing small surface to the air is to be preferred. So long as a planter depends mainly upon the action of animal organisms developed in stagnant water to lay bare his plant to the solvent action of water, a larger surface may, perhaps, be on the whole desirable; but if the plant can be got at by the water under the influence of convection currents, caused by heat applied near the bottom of the vat, then the necessity for depending upon animal organisms disappears, and the more the surface exposed to the atmosphere can be contracted the better.

Hence, with my method of heating the steeping vat, a deep vat is better than a shallow vat, from this cause. Also, if a dead weight is used as pressure in the way before pointed out, all danger from over violent upward pressure disappears. Also convection currents will operate more effectually in a deep than in a shallow vat. Also, with the method of packing above advised, the whole internal structure of the vat contents will be fairly uniform, and though there will still be somewhat closer texture of plant immediately below the weight than elsewhere in the vat, the plant will not be so densely matted in that region as to oppose any very serious obstacle to the free escape of gas bubbles, and it will be found that so far from the plant rising out of the liquor as the steeping goes on, that the weight will, after a short time, sink down to a lower level in the vat, carrying the plant before it, and when the liquor comes to be drained off, the weight will subside, and thus materially assist in squeezing out part of the liquor which might otherwise remain adherent to the plant and be lost, together with its contained indigo, when the plant was cleared out of the vat.

The objections on account of the necessity of having to raise the plant bundles to a higher level, and of having to pump water to a greater height, are of small moment, as the extra cost from these causes will be infinitesimal; and the increased difficulty of packing and unloading a deep vat will be minimised by using firmly-tied bundles of uniform dimensions, which can be packed, like sacks of grain, side by side, layer above layer (always on end), and unpacked by hooking them up by their belly bands.

Accordingly, in every factory where it is proposed to use my method of warming up the vat after it is charged, I would suggest the advisability of raising the side walls of the vats to two or three times their present height, so as to convert a 1,000 cubic feet vat into a vat of 2,000 or 3,000 cubic feet.

When this is done it will be necessary to look to the strength of the existing masonry, because every extra foot of water in vertical height will add an extra pressure on the structures below of nearly half a pound to the square inch.

This consideration will, among others, impose limits upon the depth which can be given to large vats, and convenience of packing and unpacking has also to be considered, so that about three times the ordinary depth will probably be found to be the deepest vat which it will be convenient to use.

Under the system above advocated, by which every vat is flooded directly it has been packed and weighted, and heated directly it has been flooded, it will seldom happen that more than one, or at most two vats, will be in process of being heated up at the same time.

The appliances for artificial heating should be so regulated with reference to the capacity of the vats that the temperature of each vat can at will be raised from 80° F. or 85° F. (the ordinary average temperature of the tank-water) to a temperature of from 150° to 160°, in the space of from one hour to one hour and a half.

It will be best always to commence the heating up gradually, then more rapidly, and when the temperature of the bath at one or two feet below the surface stands at 150°, it may be allowed to rest for about ten minutes preparatory to drawing off, so as to give time for suspended dust particles to settle on the plant.

So soon as the vat has been drawn, and sufficient time allowed for all the liquor to drain off which will drain off, the weight may be immediately taken off, then the bamboo framework, then the plant bundles may be taken out and transported to some convenient place near by, where they can be opened out and left to dry, the fragments of rope being kept to be used over and over again, until they grow too rotten to bear the weight of a bundle of plant.

There is no use in attempting to get a second crop of produce from the same lot of plant by a second wetting. The yield would be so excessively small as not to afford any sort of adequate compensation for the loss of time and power which the second steeping would entail. Practically you would get next to nothing. This many planters have learnt by practical experience to be the case, though most people I have talked to on the subject have not been able to understand why a fair second crop of indigo could not be obtained, and until I had embarked upon my somewhat elaborate investigations, I thought, as I believe many planters still think, that the plant must even yet contain a large quantity of indigo after the first brew of liquor was drawn off.

Now, however, I am convinced that this is not the case. The plant will, of course, be wet after the first brew has been drawn off, and the liquor with which it is wetted, as well as the liquid which permeates it in all its parts, will be charged with indigo, and be at least as rich in that substance as the liquor which has just been drawn off. Of these facts there can be no reasonable doubt; indeed,the liquid in and immediately in contact with the plant might be supposed to be at least fractionally richer in dye-making material; but the total quantity of this liquor remaining with the plant bears such a very small ratio to the quantity drawn off, that, even if it were twice or three times as rich in dye stuff, which it probably is not, and even if it were possible to collect it all, the quantity would still not be worth recovering at the expense of having to fill up the vat again with water, and of having to oxidise it out from that water.

The indigo plant is a thoroughly non-succulent, non-spongy sort of plant.

The actual density of the plant, as before stated, is not very much less than that of water, and the leaves after soaking have a density slightly greater than that of water, but the structure of the plant is such that, to flood a small quantity of it, very many times its weight of water are required, no matter how closely it may be packed; and, when this is ultimately drawn off, the quantity left in or adherent to the plant forms only a very small fraction of the whole quantity.

But the indigo in even this very small residue of liquor cannot be abstracted by a second washing, because, as the first lot of liquor drained off, air followed it down, and, coming in contact with the films covering the surfaces of all the leaves and stems, the air will almost immediately have oxidised and rendered insoluble the minute quantities of indigo in those films. This little indigo, therefore, and the indigo which had been precipitated at or near the surface of the vat from the liquid there exposed to air, will be lost, and it is useless to think of recovering it by a second washing. The loss due to adherent films will be lessened to some extent by the use of a dead weight, as before explained, and the loss from surface oxidation may be minimised by limiting the surface area with reference to the total volume of the vat. For the rest, the liquid which is drawn off should, if the plant has been properly steeped, carry with it to the oxidising vat nearly all the indigo-forming constituents of the plant which has been steeped. After all parts of the plant have been exposed to the solvent action of water for a very short time, the water will have exerted its full solvent action on the plant; and, if longer steeping produces more copious quantity, it can only do so at the expense of quality. As a rule, short steeping by the old process gave purest colour and small quantity; long steeping, large quantity and bad colour. If you only steep the plant long enough, you will at last succeed in getting a plentiful filthy produce of almost a black colour, consisting of organic matter mixed with indigo; but the total quantity of indigotin which can be extracted from this produce of over-steeped plant will not exceed the quantity which could have been obtained from plant steeped for the correct time.

This concludes all that it seems to be necessary to say now about the first stage of manufacture, except as regards water supply, which will be treated of in the next chapter; but, before passing on, I would again warn my readers not to look for possible improvements in genuine produce as a result of doctoring the vat with chemicals. Some chemicals which have been proposed from time to time have been demonstrably only adulterants of the indigo; others have been added with reference to fanciful theories about imaginary fermentations which were supposed to evolve the indigo. So far as I know, the only chemicals which have ever been found to be of the slightest real service in the steeping vat have been chemicals whose ordinary effect in the laboratory is to arrest oxidation, as sugar, for example. When such chemicals are used, the period of steeping may be prolonged, but they also retard the later stages of manufacture; and are more harmful than useful to the planter who uses them, and by far the best plan to check oxidation in the steeping vat is to restrict the surface area of the vat.

Experiments to Illustrate Chapter I.

Theory of Steeping Vat.

(1) Take a sprig of fresh indigo plant, hold it by the stem, and plunge the whole into a bath-tub full of water; hold it there for half a minute or minute, then withdraw it.

You will observe that the leaf surfaces have not been wetted by the water, and water drops on the leaves will run off in globules, like water off a duck's back.

(2) Pack inside a peg-glass, or, better, a large glass

water-jug (the larger and deeper the better, if quite clear and transparent), some fine shoots and leaves of indigo plant; then lay a moderate weight of metal or clean stone on the tops of the leaves, then pour on water to cover the leaves and weight.

Observe how the immersed leaves all have a silvery appearance on their surfaces from the films of air which separate the leaf surfaces from the surrounding water.

Observe how long a time will elapse, if the glass be left to stand at rest in one place on a shelf or table, before the silvery-sheen appearance will disappear, and the leaves acquire that apparent bright green colour which will indicate that they are at last wetted, and that the air has ceased to separate the water and leaf.

Note the escape of bubbles from the leaf surfaces through the liquid. Note the formation of a film of blue indigo on the upper surface of the liquid at a later stage in the steeping. Observe the gradual development of a cloudy appearance in the upper parts of the liquid and the gradual penetration of a (1) bluish, (2) greenish, (3) yellowish milkiness downwards from the surface towards the clear yellow liquid below. Draw off with a pipette a drop of the cloudy fluid from near the top, and examine it under a microscope. Compare this with a drop drawn by another pipette from near the bottom.

(3) Take a freshly gathered leaf and examine one of the leaflets under a microscope, both by reflected and by transmitted light, taking care not to handle the leaflet to be examined. Observe the hairs and their distribution over both surfaces of the leaf, and especially over the lower surface. Observe, also, the distribution of the stomata.

(4) Take a handful of freshly gathered shoots and leaves and mash them up quickly with a pestle and mortar, adding a little water to make a thin paste.

Strain this thin green paste through a fine handkerchief, and beat up the strained liquor with a fork in a soup plate. Observe that indigo will be oxidised out of the juice.

Note the absence of any symptoms of fermentation. Note the short time in which indigo blue begins to appear. The process of bruising the leaves in the mortar and moistening and straining need not occupy more than a minute or two. There will thus be no time for fermentation, as there are also no symptoms of fermentation, but the strained liquor will contain indigo-forming material; and, if this strained liquor be then rapidly filtered through filter paper under pressure, it will be found that ordinary blue granular indigo will separate out from the clear filtrate on oxidation, the time required for oxidation being about the usual time required for oxidising indigo, according to the method of oxidation employed.

Observe, also, how very little time is required for the indigo-forming substance to be dissolved out from the leaf mash by the water when the two are brought into intimate contact through the agency of a pestle and mortar.

(5) *Take a large test-tube or boiling-tube of thin glass*, fill it three-quarters full of freshly gathered indigo leaves, and pour in water till the liquid rises above the level of the leaves in the tube.

Observe, as in the experiments 1 and 2, that the leaves are not wetted by the cold water, as evidenced by the sheen at their surfaces.

Proceed to warm the tube at the bottom over a spirit-lamp; note, during the process of warming, how bubbles of gas escape, and gradually the leaves get wetted all over, as evidenced by the change of appearance (or, as you can satisfy yourself by repeating the experiment and taking out the leaves when this change of appearance is first observed). Note that, by the time the temperature of the tube contents approaches boiling point, even though this should be within two or three minutes only of the commencement of the heating, all or nearly all the leaves will be wetted. Pour off the clear liquor then, immediately, into a saucer, and beat it with a fork, when you will find that it will afford a good yield of very pure indigo.

Note how clear the liquor is when decanted, with a complete absence of milkiness (*i.e.*, if you have not used dirty or dusty leaves).

Note specially the exceeding short space of time in which the indigo-forming substances can be abstracted from the plant in this experiment.

Observe the absence of fermentation. Satisfy yourself that the time consumed in the process of extraction is only the time necessary to bring the liquid into effectual contact with the plant for a minute or two, and satisfy yourself by reading, or by experiments on bodies which are known really to ferment, that true fermentation is a slow process requiring time, and not in any known instance a process which can be completed in a minute or two.

Repeat the experiments in various forms with test-tubes and flasks, and satisfy yourself that most of the air bubbles which rise to the surface during the warming arise from the surfaces of the previously unwetted leaves, and that, if the heating be not pushed to the boiling temperature of water, few, if any, bubbles will rise after the leaves are seen to be completely wetted.

(Note, ordinary cold water always contains a certain quantity of dissolved gas, such as air, carbonic acid gas, &c., these gases the water parts with on heating, whether there be any plant in the water or not, but this quantity is in common water not great, and should not suffice to mislead in your observations. You can get over to a great extent this possible source of confusion in your experiment by first boiling the plain water in the tube to expel dissolved gases, then let the tube with its contained water stand perfectly still till it has cooled down to the temperature of the atmosphere, then drop into the tube a freshly gathered compound pinnate leaf of indigo plant which has not been handled except at the base of the petiole (leaf stalk). As this will not sink unless weighted, a small piece of copper wire may be twisted round or tied on to the base of the petiole to sink the leaf, which will then stand with all its leaflets erect in the tube. Now warm the bottom of the tube over your spirit-lamp, and observe how the individual leaflets get cleared of their adherent films of air, and how, if you will cease to apply heat after the whole surface of all the leaflets is wet, there will be no further escape of bubbles from the leaves. This experiment should be performed in a room by lamp light, or in diffused daylight, because in strong sunlight a distinct class of chemical operations come into play under the combined influence of sunlight and chlorophyl (the green colouring matter of leaves), and these give rise to a slow evolution of gas bubbles; but this reaction is not fermentation, and is common to indigo leaves and to all green leaves of all or nearly all plants.)

Repeat the experiment again with a number of leaves, warming up the tube till all the plant is observed to be wet. Note, again, how the bubbling falls off as most of the leaves are wetted. Continue warming intermittently for a few minutes, until it is fairly certain that none of the leaves which are obscured from sight are still unwetted; and now, instead of at once pouring off the liquor, stand the tube upright and let it rest in a place where you can carefully observe it while it is cooling. You can then see that there is no regular continuing escape of bubbles, as there would certainly be if any process of fermentation were going on of such a character as to develop gases during the fermentation.

When the tube and its contents have cooled down to the atmospheric temperature, pour off the fluid contents into a saucer, and oxidise by beating with a fork. You will get indigo as before, in proportion to the quantity of plant leaf used, and the quality will be of the very best.

Before pouring off the liquor, note the film of oxidised indigo which has made its appearance at the surface of the liquor in the tube which has stood some time, and note that there has been no visible precipitation of blue indigo anywhere but at the surface exposed to the air.

These experiments under heads four and five should abundantly suffice to satisfy you that no process of fermentation is necessary for the production of indigo blue. I hope they will satisfy you that the fermentation theory of the steeping vat is quite untenable, and, further, these experiments, in conjunction with those which have gone before, all go to support my theory of the vat as put forward in this book, now, I believe, for the first time.

(6) Dry some indigo leaves by spreading them out in the sun. When these leaves are quite dry, pound them into a fine powder in a mortar. Then pour tepid water on this powder, stirring them well together to secure that the whole of the powder shall be wetted as quickly as possible. As soon as it is all thoroughly mixed into a paste, strain through a fine cambric handkerchief. The fluid which comes through will, on oxidation, yield a fair crop of indigo.

In this case, of course, the plant hairs could not operate to entangle any air films to protect the plant.

The pounded plant could be easily reached in all its pa by the water; solution of the contents out of the sol powder, will take a little longer than solution out of previously moist mass, but it will be very quick, an there is nothing to indicate that any fermentation take place.

In this case, if fermentation were to take place at all, the only time there could be fermentation would be while the leaves were being dried. In reality, there is nothing to show that there has been any fermentation during the process of drying; but, if this experiment were to stand alone, it might be fairly said that the plant may have fermented to a certain extent while drying. In various printed articles and books treating of indigo manufacture, it has, I believe, been stated, with reference to the Madras method of manufacture from dried plant, that the plant undergoes some kind of fermentation in drying.

I would point to the absence of any satisfactory evi-lence in favour of fermentation theory; and it will be een at once that the results of this experiment are alto-ether consistent with my theory—that it is only neces-ury to secure access of water to the plant to enable the ater to dissolve out the substance already there existing, ich will, on oxidation, yield indigo blue.

The pounded dry plant is the common wasma of Upper lia. It spoils rapidly, if it is allowed to get damp, n exposed to the air. The reason, of course, is ous. Before the leaves were pounded, and after commenced to be dried, the unbroken epidermis of eaf formed a protective coating for the inner con- of the leaves, which prevented access of air se contents; but, when the dried leaves have been ed up, air and moisture can alike penetrate every-

Moisture brings the indigo-forming substance into solution, and air oxidises and causes blue indigo to deposit on the moist particles of the powder. Hence moist wasma, which is bright bluish green at first, when good, turns nearly black after it has been exposed for a time to the air. It may be observed here that the indigo obtained from wasma, or from bruised plant, or even from dried plant which has not been intentionally bruised, will ordinarily be inferior in point of colour to indigo obtained from clear infusions of the fresh plant, the reason being that it will generally be more contaminated with chlorophyl and other vegetable matter. Chlorophyl is green at first when fresh, but on oxidation or exposure to light changes to shades of yellow and brown, which tints, mixed with indigo, tend to produce shades approaching to black.

These experiments are not, of course, quoted to show that equally good quality indigo can be obtained by all these methods—the one main principle which all these experiments go to demonstrate is that the indigo-forming substance, whatever it is, exists in the plant ready formed, and whenever water comes in contact with it, it will dissolve it out of the plant; and the experiments serve to explain why the ordinary steeping process, as practised in Bengal and Tirhoot, is so lengthy, and to indicate how the steeping process may be shortened.

It is interesting also to reflect how that, if the leaves of the indigo plant were not protected as they are, then any substance having the properties of the indigo-forming substance in the plant could scarcely be expected to be found therein after even a very moderate downpour of rain. Hence from *à priori* consideration it might have been expected that the leaves would be provided with some kind of protective arrangement, such as they do in fact possess, and that arrangement, like so many other arrangements in Nature, is beautifully automatic. The leaves have the greatest resisting power for water just at those times when an approaching rainfall is most probable, *i.e.*, when the hygrometric state of the atmosphere stands at its highest, and, as the leaves dry up in a dry atmosphere, their resisting power becomes progressively less and less, until at last, when the leaf has been thoroughly dried, there is but very little resisting power left. These facts can be observed and *experimentally illustrated*, and are interesting, but we cannot spare time and space to go into them in full detail here; but it must be remembered that before you can get the indigo out of your plant, you have to overcome a very beautiful natural arrangement for protecting the leaves of the plant against the too close approach of water.

(7) With reference to the remarks last above made and the importance attached to plant being all approximately of equal freshness in any given vat, you should, some day during the rainy season, walk into an indigo field while rain is falling, and observe how effectively the leaves throw off all the raindrops which strike them, and, when the rain is over, cut a few of the freshest-looking sprigs and carry them quickly home. Try some of these fresh sprigs in your bath-tub or in a jug, and note how mere immersion, or even immersion accompanied with a fair amount of internal agitation, will quite fail to wet the plant. You may move the plant up and down and backwards and forwards some scores of times before the leaves will get wetted.

Now take a fresh leaflet and compress it firmly between your thumb and finger, or lay it on the palm of your hand and rub the leaf surface with your finger, and re-immerse in water, and note how *much more* easily these leaves are wetted.

Now, take a sprig of stale plant, if you have any at hand—some plant, that is, which has been gathered a long time before—or take a piece of what is technically called burnt plant, and test that similarly by immersion or movement under water, and note how it is less difficult to wet.

Now, take a small lot of your very freshest and best leaf and pack it lightly in a peg-glass, and a corresponding lot of stale or burnt leaf in another peg-glass, and pour water from the same jug or gharra upon both lots at the same time, and put them aside to steep quietly under similar conditions. Then, at intervals of every few hours, draw off by pipettes corresponding small quantities of liquor from each glass, and compare the progress made in the steeping.

Also observe, through the walls of the glasses, the appearance of the plant and liquor inside; and, finally, allow both glasses to remain charged and to stand in the same places until the plant passes to the stage of being decidedly over-steeped in each, and note when this occurs in each case.

CHAPTER II.

WATER.

In Chapter I. it has been shown how that the really essential requisites for the manufacture of good indigo are, in the first instance, good plant and good water.

Without good plant or good water it is useless to hope that you can make good indigo; and, having given these essential requisites, the process of manufacture consists, in the first instance, in bringing the plant and water together under such circumstances that the water can really get at the plant.

If this can be satisfactorily effected, then the water will dissolve the indigo-forming substance out of the plant, and the next stage in manufacture will consist in getting the blue indigo precipitated out of the water solution, and all subsequent stages resolve themselves into mechanical arrangements for accumulating and cleaning and drying and working up the indigo into convenient blocks to be sent to market.

It is, therefore, evident that when it is proposed to erect a new factory, the site for the factory should be so chosen that it may occupy the most convenient position possible with reference to the lands on which indigo plant is grown, or about to be grown, and also with special reference to the abundance and quality of the water supply which can be made available for factory use.

When the site has once been decided upon and the factory built, satisfactory transport arrangements should be organised for getting in the plant with as *little delay, as much regularity, and as little cost* as is possible, and similarly the whole water supply system should be so arranged that there may be a never-failing supply of good water when it is required for use.

The details of the water supply arrangement will vary greatly with the circumstances and situation of the factory, and can only be settled by careful consideration of those details on the spot, but there are certain considerations of general application which can with advantage be treated of here.

In the first instance, it can be affirmed generally that for the indigo planter's purposes soft water is good water as contradistinguished from hard water.

The indigo plant forms no exception to the general rule that vegetable infusions are best made with soft water.

If it were possible always to command a sufficient supply of clear, fresh rain water, this would be the best water supply possible for indigo manufacturing purposes; but, of course, this is not possible, and ordinarily the best practical source of water supply is from a running stream, especially from a stream which is fed mainly by the rainfall in neighbouring hills or by melting snow or ice.

Spring water is commonly hard water, and the water of a running stream may be hard if that stream is mainly fed from springs. Also the water of a running stream may become hard when it passes over certain kinds of rock, or receives drainage water from a highly calcareous soil.

Hence streams vary very much in quality for indigo-making purposes, and while some few streams may afford a steady supply of remarkably good water, others differ very widely among themselves, and some afford water of very different degrees of goodness and badness at different seasons and in different years.

A prudent man, before deciding to erect a factory on any given site, would give very careful attention, not only to the quantity and regularity of the water supply, but also to the quality of the water, and would have copious specimens of the water analysed by the most reliable and experienced analytical chemists, if he could not effect satisfactory analysis for himself; but there are many factories which have been erected without any such preliminary careful investigation, and some of those factories have had for many years a regular supply of bad water, which has placed them at a disadvantage as regards other factories more fortunately or more judiciously placed.

Others, again, though these are very few indeed, have started with good water supply years ago, but the quality has deteriorated since, and there are some where the quality of the water supply varies in different years.

For the managers of all such factories it is a matter of importance that they should acquire a sufficient practical knowledge of the rudiments of chemistry to enable them to test their factory water accurately, to determine what is wrong with it, and to apply to the water such simple remedial measures as will render it better adapted for factory work.

Indeed, if every indigo planter, when he is lucky enough to be able to go for a run home, would devote only a small portion of his holiday to the study of practical water analysis under competent European teachers, the time and trouble and money thus consumed would in a majority of instances return interest a hundredfold in India, in the shape of increased produce of purer quality, and individual planters would not be so likely to fall into the hands of adventurous charlatans with a very little real knowledge of chemistry, and little or no knowledge of anything else.

I think that every factory of any dimensions should be provided with one room at least as a laboratory, with a specimen-room adjoining, and the laboratory should be provided with weights and measures, and standard specimens for comparison, as also with lenses, a microscope, a liberal supply of thin German glass flasks and beakers and test tubes, and carefully prepared standard solutions specially prepared for the rapid quantitative analysis of water by the volumetric method, and a sufficient collection and supply of common chemicals.

To facilitate working and to aid memory and save time there should be regular printed forms to be filled in, and uniform standard methods of testing to admit of easy comparison of results.

Such laboratories unfortunately do not, I believe, exist in most factories, if in any; but their general introduction would be an improvement, and the expense of each would be small.

In these modern days the rudiments of chemistry and physics are taught in all or nearly all good schools in England and abroad, and in future there should be no great difficulty in requiring from young assistants who wish to become indigo planters that they should be able to analyse water and indigo, and be more or less competent to analyse soils, manures, &c., when required; and in the meanwhile, if there were a sufficiently equipped laboratory at each large factory, there should be no difficulty in securing the services of a competent chemist (duly certified by some recognised English authorities) to visit in regular sequence a series of factories, which would each contribute a share of his pay.

At present one often hears complaints that there is something wrong with the water supply at a factory, and the people who make these complaints are at a loss to know what to do, and either let matters slide by continuing to use what they believe to be bad water, without even attempting to remedy, or to get remedied, the defects, or even to ascertain what they are; or they try quack remedies of all sorts on the recommendation of chance adventurers who dub themselves chemists—persons, sometimes, who really know very little of chemistry, and less of the theory and practice of indigo growth and manufacture than the planters themselves.

Such mistakes would not be made, if the planters were themselves competent chemists, and they would also not be made on a large scale if the planters would insist on seeing tested in the laboratory on a small scale the methods which they are asked to apply to the factory vats on a large scale.

With reference to indigo manufacture, you can literally do in a cup and saucer on a small scale what you do in 2,000 cubic feet vats on a large scale, and small model vats of 20 cubic feet capacity will enable you to make exact quantitative experiments as regards time, quantity, quality, and everything else you may wish to ascertain, with as much precision as the very largest vats made.

Hence, in connection with laboratory experiments, it will often be well to have small experimental sets of vats, and only when you have ascertained by experiment in those vats that any proposed innovation is a real improvement, should it be applied on a large scale to the manufacturing ranges.

In order to keep your water supply under proper observation and control as regards its quality, a laboratory, with a few simple appliances, is a matter of necessity; but, having a laboratory with these simple appliances, nothing is easier than to determine all that you require to know about the water, and you will generally be able to determine what exactly should be done to the water to improve its quality for your purposes.

For example, if you have a standard volumetric soap solution and a graduated burette, you can, in a few minutes, determine the exact degree of hardness of a measured quantity of water when fresh from your reservoir (say one gallon) and filtered before adding the test. Also, if you have a standard volumetric solution of potassium permanganate and a burette, you can in a short time determine the amount of oxidisable organic impurity in your water.

By evaporating a measured quantity (say two gallons) of your water to dryness over a water bath, having first filtered the water through filter paper, and collecting and weighing the solid residue, you can determine the total solids dissolved in the water.

By filtering a large measured quantity of water fresh from your reservoir through a previously weighed filter, and afterwards, when the filtration is over, reweighing your dried filter with the contained sediment, and calculating the difference, you can determine the total solids in suspension. By precipitating with solution of oxalate of ammonia, you can determine the total quantity of lime in solution. By precipitating with solution of chloride of barium, the total quantity of sulphuric acid. By precipitating with solution of nitrate of silver, the total quantity of hydrochloric acid, and so on.

Time and space will not admit of any lengthy exposition here of the methods of water analysis, and the reader is recommended to refer to standard chemical treatises for fuller information on that subject; but, ordinarily, the planter will not need to trouble himself with the refinements of water analysis. He will generally only need to know what impurities his water contains in any quantities which are likely to spoil it in any degree for his purposes. The best ordinary practical test to apply to the water is to add, from a graduated burette, a clear, saturated solution of lime water to a gallon of the water to be tested, so long as the lime water continues to give a precipitate. Then read off the quantity of lime water used.

This experiment, if carefully and accurately performed, will enable you at once to calculate, with a very fair approach to exactness, how much of a saturated solution of lime water must be added to the main supply of water in your reservoir in order to precipitate the carbonate of lime which it holds in solution.

Hard water is commonly rendered hard by carbonate of lime held in solution in the water by excess of carbonic acid gas. When lime water is added to such hard water, the lime of the lime water seizes on the excess of carbonic acid gas in the water, and is precipitated as carbonate (chalk); while the carbonate of lime, which was previously dissolved, is also precipitated, because there is no longer any free carbonic acid gas in the water to continue to hold it in solution. Hence, the apparent paradox, that by adding lime to water you deprive water of the lime it had before in solution.

It is important not to add any considerable excess of lime water, or it may turn out that the remedy applied is worse than the disease it was sought to cure. The proper quantity to add is just sufficient to complete the precipitation and no more, but it is better to add too little than too much; because, if you add too little, the only result will be that the water will have been partially and not thoroughly softened, but, if you add too much, you will have in solution a corrosive alkaline earth, which will be more injurious in the vat than a little carbonate would have been.

In every factory where the water is naturally hard from dissolved carbonate of lime, there should be a small tank near the water reservoir in which to make the lime water. The lime should be burnt somewhere near the factory, and, immediately it is slaked, it should be transferred to the lime water tank, which should be kept filled up with water, covered so as to protect it as much as possible from the air. In this way it should be possible always to keep on hand an abundant supply of lime water ready for immediate use. The lime-water solution should always be added to the water in the reservoir in definite measured quantity, calculated from the result of your test experiment on one or more gallons, as before described. The water in reservoir which has been softened by lime water should then be allowed time to settle, or it should be filtered.

In practice it will rarely happen that you will need to subject your main water supply to any other action than precipitation by lime and filtration, and it would seldom pay, even if it were necessary or advisable, to subject water in your reservoirs to any more complicated or expensive process; but it is a matter of surprise that this very simple and inexpensive method of softening the water is not more commonly adopted, and more especially is it surprising that water for factory purposes is so very seldom filtered.

Filtration separates at once all solid impurity, organic or inorganic, and the cost of filtering the whole water supply for the whole season would ordinarily be so exceedingly small that it should certainly pay to filter the whole of the water before it goes to the vats.

The water of swift-running streams is commonly charged with sediment, mostly inorganic, and the water of slow streams or stagnant water often contains excess of organic matter. In both cases the water would be better for having been filtered, yet I believe that at some factories running and often muddy water is pumped straight from the stream to the vats, occasionally without the intervention even of a subsidence tank.

A better arrangement is to let the water from the running stream flow gently by a side channel into a large subsidence tank, which is nothing more than a very large kucha tank, with its base at a much lower level than the bed of the stream from which it is filled, and its sides higher than the water level in that stream. This tank is filled, in the first instance, by opening the water gate in the cutting which leads to the supply stream. At the first inrush, and for some time after it is filled, the water will remain muddy, but most of the mud will gradually subside, and afterwards, if water is led off through a pucca channel, communicating only with the upper portion of the tank, that water will flow off moderately clear. In practice the channel from the supply stream is often kept open while surface water is being drawn off from the opposite side of the tank for use in the factory, but the mud coming in with the stream water mostly subsides in the tank before the stream water or any part of it reaches the factory outlet.

This arrangement is fairly effective, but it does not give absolutely bright, clear water, and the sediment carried in to the vat by this water is just of that fine impalpable kind that a large part of it will be carried out again into the oxidising vat when the liquor of the steeping vat is drawn off. For very coarse sediment the plant in the steeping vat acts as a moderately efficient filter, and some planters rely so much on the filtering and straining power of the plant, that they do not sometimes hesitate to let distinctly muddy water into their steeping vats; but it is well to bear in mind that the finer the sediment the less of it is stopped by a coarse filter, and also that all fine sediment, which ultimately finds its way down into the oxidising vat, will there tend to get blended with the indigo, from which it will never again be effectually separated at any subsequent stage in manufacture.

My opinion is that while an intermediate subsidence tank is an excellent mud-trap for arresting all the coarser and heavier forms of inorganic sediment, its use should be supplemented by employment of an efficient filter to separate all the finer particles which have not subsided by their own gravity, and the plant in the vats should be fed only with perfectly clear water.

The filtration of large volumes of water for factory purposes is an exceedingly easy and by no means costly operation.

A very simple filtering arrangement can be constructed as follows :—

Build a small pucca tank close to the large reservoir whose water you wish to filter. The depth should be some ten or twelve feet greater than the depth of the main reservoir whose water is to be filtered, and the upper margins of the filtering tank should be on a level with the upper margins of that tank. Next build a stout masonry partition across the middle of this small pucca tank so as to divide it into two halves, either transversely or diagonally, it matters little which. Into the base of this dividing wall there should be placed a large number of metal pipes. Galvanised iron pipes such as are commonly used as water pipes will answer quite well, or the pipes may be dispensed with, if the masonry itself is perforated by good pucca channels, but it is essential that by means of pipes or perforations there should be free transit for water from one side of the partition to the other at the base of the wall, and that the arrangement adopted for securing this free transit should be such as not considerably to weaken the power of the wall to bear considerable lateral pressure.

Having constructed this tank with its partition perforate below, but imperforate everywhere else, proceed to spread over the floor of the tank, on both sides of the partition equally, a layer of old scrap iron, nails, &c., to a depth of, say, one foot. Then spread over this a layer of rounded particles of hard rock (not limestone), then smaller pebbles, the pebbly layer to reach a foot or a little more in thickness.

Then a layer of about a foot of coarsely crushed charcoal, then clean, bright sand to fill up the small filtering tank to about the level of the base of the tank whose water is to be filtered. The filling in of the tank on both sides of the partition should be the same. The iron scrap and the charcoal are not either of them strictly necessary, but they are both of assistance in freeing the water from soluble organic impurity, and the iron will deprive the water in part of any free oxygen gas which it may contain (a pernicious substance in the steeping vat). Generally iron scrap and old nails can be obtained without difficulty; but if there is any difficulty, omit them.

Charcoal can be obtained in nearly every bazaar in India, and I would advise that the charcoal should not be omitted; but gravel and sand alone will give you clear water, and suffice to separate all matter merely suspended in water, such as mud or living organisms, animal and vegetable.

It will be advisable always to have a depth of several feet of sand, so that, if the surface gets disturbed, there may still remain a sufficiently deep layer for necessary purposes. Having constructed your filtering tank, as above stated, you have only to connect one half of it by one or more large pipes with the water supply you desire to filter. Water will then flow through these pipes into that side until the level there is the same as in the reservoir from which it comes, and the muddy water which has so entered will be strained or filtered in passing down through the sand, &c., and after passing through the perforations in the base of the partition wall will again rise through the corresponding layers on the other side, and ultimately reach the same level as on the opposite side and in the reservoir.

Directly any of the filtered water is drawn off, more water filters through to supply its place.

Through such a filter many thousands of cubic feet of water can be passed daily.

The water filters fastest at first, and when the filter has been newly constructed and freshly filled or recently cleared, the water will sometimes run a little muddy for a few minutes only: but afterwards the filter will give a perfectly clear water, and the only attention it will ordinarily require will be to run off the water periodically from above the surface of the sand (having first stopped the tube leading from the large reservoir of unfiltered water), and then to scoop off the upper layers, which are charged with mud and slime, and replace what is removed with fresh clean sand.

In order to allow of this cleaning being done with interrupting the water supply, it will generally found convenient to have two similar small filteri tanks, which will ordinarily be used alternately, b which can both be used at once whenever there is a immediate demand for a particularly large supply o filtered water.

The pipe which communicates between the reservoir of unfiltered water and the filter should open in the reservoir below the surface, but not too near to the bottom. If it opens too high, then, besides the fact that it will fall out of use altogether when the water level sinks a little, it will also allow floating particles of dust and dirt, &c., to pass towards the filter; while, if it opens too near the bottom, it will afford transit to an unnecessary amount of mud, and this is a decided disadvantage, because the more mud passes into the filter the more quickly will it get clogged and require emptying and the change of the uppermost layer of sand and removal of the filth above it.

The communicating tubes should, of course, be rovided with terminal strainers to prevent the free ıssage of grass, leaves, &c.

By interposing filters of the kind described between subsidence tank and a large pucca reservoir, conucted at about the same level as the subsidence k and filter, there will always be a liberal supply of r filtered water ready for use in the pucca reservoir never the subsidence tank is full or nearly full. pipes leading to and from both sides of the ing tank must, of course be efficiently plugged whenever the filter is to be cleaned, or for any other reason thrown out of use.

It must be remembered, also, that the level of the water in the subsidence tank, or other tank whose water has not been filtered, must never be allowed to fall below the level of water in the filter tank or in the reservoir tank containing filtered water, so long, that is, as the communicating pipes are open, otherwise there will be a back flow.

The best arrangement of tanks, when water from a running stream has to be used, is, therefore, to have, first, a large kucha subsidence tank receiving vater by a side cutting direct from the running tream; second, a small pucca filtering tank, or, etter, a pair of such tanks constructed as above escribed, and in communication on one side with the ater in the subsidence tank as far off as can be conniently arranged from the inflowing muddy current; d, thirdly, a large pucca reservoir tank to receive d hold the filtered water. These tanks should all on the same general level at their upper margins, hat whenever the communicating pipes are open re shall always be a free passage of water from subsidence tank through the filter to the pucca rvoir tank.

s before stated, the water may sometimes be hard ell as not clear. In every such case the reservoir of filtered water will be the proper place to soften ater. The way to do this is sufficiently simple, as been above explained.

capacity of your reservoir tank will, of course be known, and by measuring accurately the depth of water in that tank, you will know exactly how many thousands of cubic feet it contains at any given time.

Then plug up the connection with the filter, through which the feed-water enters, and add the requisite quantity of clear lime water, having previously determined by experiments on a small quantity, how much must be added to treat the whole. Then pump the softened water through another filter into your overhead reservoir, if you have one.

This second filtration may be conveniently effected by means of a pucca well at that part of the tank which is nearest to your overhead reservoir. The well should be some eight, ten, or twelve feet deep, measuring the depth from the level of the base of the tank. The tube for pumping up the water should dip into this well to within a foot of the bottom, resting there on a layer of coarse rounded pebbles of hard rock.

Above this should be a layer of finer pebbles, and above this, sand to fill up the well or nearly to fill it.

The base of the tube should be provided with a perforated strainer as usual, and the upper part of the tube should be connected with your centrifugal pump or whatever other machine you may employ to pump up the water. By this very simple arrangement of a well in the tank (to the lower part of which the pump dips), filled with gravel and sand, you can effectually filter all the water of the tank, so that the pumped-up water will be delivered to the overhead reservoir free of the chalky sediment which had been formed after adding the lime water.

The cross section of the well should not be less than from twelve to twenty times the diameter of the pump pipe. If the cross section is too small the water may not filter fast enough to afford full scope to the pump, especially after it has been in use for a short time.

The main objection to a well filter in the tank itself is that it cannot be got at to be cleaned, except when the tank is empty, but if the overhead reservoir is sufficiently large, this may not be a serious objection, as there need be no waste of filtered water and no delay in the working of the factory, if, once in every few days during the season, the pipes coming from the filter tank are closed and the whole of the water of the low lying pucca reservoir be pumped up through the well filter into the overhead reservoir, so as to lay bare the bottom of the tank and allow the well filter to be cleared by removing the upper foot or so of calcareous slime and sand, adding some fresh clean sand in its place.

A well filter is not suitable for use in the subsidence tank, because, that tank being only a kucha tank, the base would always be covered with enormous quantities of mud, and such a well would get choked up almost immediately.

Often stream water can be obtained perfectly clear at the outset by the very simple expedient of sinking wells at a short distance from the bank of the stream, and so making use of the porous earth as a natural filter.

When the earth below and on both sides of the running stream is sandy, this is by far the best and simplest and cheapest way of getting the water, and the subsidence tank and the tank filter can be dispensed with altogether, the clear water from the well being then pumped straight into the first of your system of reservoirs, or into your only reservoir if you have but one. Sometimes it may be found to be worth while to sink a series of wells in the dry, sandy bed of a running stream.

An objection which may arise in the case of most wells is that, if water is pumped up rapidly in large volumes, the water-level may rapidly sink in the wells, so that after a short time you can pump no more without first giving the well a rest. This will always happen when the rate at which water is pumped out is greater than the rate at which fresh water can filter through the earth to replace that which has been pumped out. In the sandy beds of streams this particular difficulty will not ordinarily arise; but if the subjacent earth is very loose or sandy, the well may get choked from sand tumbling in, or getting sucked in by the inflowing water. These various matters have to be considered with reference to the particular circumstances of the situation of each factory. In every event it is necessary that the water-supply arrangements should be such that there is no danger of failure of water, or of short supply of water, during the manufacturing season. Water may be kept waiting ready to be used on indigo plant, but you cannot keep the plant waiting for water without incurring serious loss.

In practice it will nearly always be found to be expedient to have large reservoirs full of clear, fairly soft water, ready at any moment for immediate use. It is also a very distinct benefit to a factory to have at least one capacious pucca overhead tank, capable of holding water sufficient to fill all the steeping vats and to spare, and high enough to dominate the whole series of vats. The cost of constructing such reservoirs is very considerable, and they require to be made very strong and pucca, so that they may not leak, and not be in danger of yielding to the water-pressure they will have to bear when full, but they will repay their cost in a very few years. Every important factory, in modern days, is provided with a large steam boiler, which supplies power for pumping water and for driving the paddles in the beating range and for other purposes, in and about the factory.

Everyone who has ever worked with a steam-engine will know that it is advantageous when once steam has been got up to find continued use for it. If the factory has no overhead reservoir it is sometimes difficult to do this, but with such a reservoir whenever the whole available power of a steam boiler is not wanted for other purposes, the steam can be turned on to the pumps to raise water to the upper reservoir, whence water can be taken whenever required, and in any quantity, by simply opening drains or conduit pipes; also an overhead reservoir affords by far the most satisfactory means of filling the steeping vats. Water has to be pumped up at some time or other for those vats, and the total power consumed in pumping into the reservoir, and afterwards letting the water run into the vats from there, is very little more than the total power consumed in pumping straight to the vats from the reservoir below. The difference depends only on a slight difference of height; and, on the other hand, there are great advantages in being able at any moment to turn on a full steady stream of water, so as to fill the vats in a few minutes, instead of being obliged to pump water to the vats as it is required.

Also pumping entails ordinarily a certain amount of splashing below the mouth of the delivery pipe, and fresh pumped water will carry a larger quantity of air into the vats than a steady stream from a reservoir would do, and this air, on principles before explained in Chapter I., can only be productive of harm in the steeping vats. When there is no overhead reservoir it will sometimes happen that plant has to be kept waiting in the vats until steam power can be spared to pump for them, or other work may have to be stopped for a time, or steam may have to be got up expressly to work the pumps, to be let off perhaps after pumping is over, and in each and every such case there is waste and thus loss.

As regards water supply, then, the practical problem is always how best to get a liberal, unfailing supply of clear fresh soft water into such a position with reference to the plant, that it can be at any time added to the packed plant with the shortest possible delay, and without interfering with any other work which may be going on at the same time.

For this purpose an efficient arrangement of tanks or reservoirs and filters and conduit pipes are necessary. At one end of this system should be the natural source of the water supply, and at the other end the reservoir dominating the steeping vats.

Sometimes it happens that stream water is not available, and only ordinary well water is to be had.

Well water has this advantage, that it is nearly always bright and clear, but it is more commonly charged with deleterious gases and mineral matters in solution than stream water. These matters are dissolved from the soil around the well, and the waters of many wells are so highly charged with carbonic acid gas and salts of lime and other matters in solution, as to be very ill-fitted indeed for an indigo planter's use. In such cases it is more than ever necessary to give careful attention to the treatment of the water. In the first chapter, the prevailing dislike for and distrust of all sorts of doctoring processes for the steeping vat have been emphasised, and it has been pointed out how that, for the steeping vat, nothing but good plant, and good water, and good arrangements for getting the plant wetted by the water are necessary, but if the only water available is not good, it is necessary to treat the water for the purpose only of removing its most objectionable impurities.

The treatment before prescribed will usually suffice, and has the great advantage of being very simple and inexpensive, but if the water contains any considerable quantity of sulphate of lime, it may be necessary to treat it with oxalate of ammonia dissolved in pure water. Oxalate of ammonia is not very costly, and an exceedingly small quantity will suffice for very large volumes of water. In this case a moderate excess will not do any harm in the after processes, but as with the lime-water precipitation before described, it will be best just to use the correct amount.

The correct amount can be ascertained by observing when the addition of more ceases to give fresh precipitation.

Occasionally, also, it may be found to be advisable to treat the water with potassium permanganate, when the available water-supply is highly charged with organic matter. This will very rarely be necessary if the filtering arrangements are satisfactory, because by far the larger portion of the ordinary organic impurities of water exist therein either in the form of minute living organisms, animal, or vegetable, or as eggs or spawn or germs, together with a certain proportion of minute particles of disintegrated dead vegetable or animal matter. Such impurities as these are stopped by an efficient filter, and only matters in solution pass through with the water in any quantities.

It may, however, happen that after filtration the water may retain an offensive smell, due mostly to the gaseous products of the decomposition of organic bodies which it holds in solution.

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The offensive smell of such water can be destroyed by the addition of a very small quantity of solution of potassium permanganate.

If it is found necessary ever to use this substance to deprive water of its organic impurities, it should always be added in such quantities that the last portions added are not decolorised, and the water continues to retain a faint pink colour. The whole should then be allowed to rest for from half an hour to an hour, and if the water continues to be of a slightly pink hue, a small quantity of dilute solution of pure sugar syrup should be added to the pink liquor to deoxidise, and precipitate the small trace of manganese which would otherwise remain in solution as permanganate of potash. It is necessary to take care that no potassium permanganate finds its way to the steeping vat. It could only do harm there, and no possible good. As a very strongly oxidising agent it would be injurious, like free oxygen or any other ordinary oxidising agent, and as the whole of the manganese would, in the steeping vat, come down in a fine brown sediment of manganese dioxide, this sediment, or, at least, part of it, would get carried out of the vat when drawn, and would contribute to adulterate and very much to spoil the colour of the indigo. In practice there is very little serious danger of much harm being done with potassium permanganate, because an exceedingly minute trace of the salt will impart a very decided pink colour to a very large volume of water, so that the eyesight will reveal its presence immediately, and it could not escape notice except by extreme carelessness; and, further, a faintly pink solution would yield only an exceedingly minute trace of manganese dioxide, too small, probably, to create any great effect. Still, it is injurious, and decidedly so, and care should therefore be taken that the water has no tint of pinkness about it when it is run into the vats.

I prefer, whenever potassium permanganate has to be used at all, to add it in decided excess to the water in the first instance, then to let the water rest for a time so as to enable the permanganate of potash to exert its full oxidising effect upon the organic matter present, then to get rid of the whole of the excess of permanganate of potash in solution by adding a moderate excess of dilute sugar syrup. The sugar solution will be found effectually to precipitate the *whole excess of the permanganate of potash in a very* short time; and if the water flows on to the steeping vats with a little free sugar in solution, this will do no harm in the vat. Another substance, which will answer as well, or better, for precipitating the excess of manganese is glycerine, only glycerine is more expensive.

Another substance for the purpose is solution of protosulphate of iron (common green copperas). None of these substances are injurious if they enter the steeping vat in small quantities.

Of course, after water has been treated with potassium permanganate, and the excess of manganese precipitated, it will be necessary to pass the water through a filter to separate off the precipitate, as, indeed, it is in every case where any sort of precipitate exists, or is made in appreciable quantity in the water. No operations of any kind for purifying water should ever be conducted in the overhead tank. That tank should never receive any water which is not fit for immediate use. All operations for purifying the water should be conducted in one or more pucca tanks on the ground level.

In the overhead reservoir there should at all times during the manufacturing season be a fairly large supply of good, clear, soft water ready at any moment for immediate use, and from that tank large delivery pipes should lead direct to the basement of the steeping vats.

In all factories which I have seen the common practice is to fill the vats with water by letting it run in at the top of the vats. This is not so good as letting in the water at the bottom.

One effect of letting water flow over the plant in a downward direction is to sacrifice a little of the indigo, though doubtless not much unless the operation of filling the tank is very slow, when the loss would be considerable.

The loss of indigo will be due to the fact that the water will carry with it a quantity of air into the vat, which has been shown to be injurious in the steeping vats, and the inflowing water, whenever it comes in contact with bruised or cut or broken surfaces of the plant, will then dissolve out the indigo forming substance, or a part of it at least, and this will be immediately exposed to the oxidising influence of the air which fills all the interspaces between the plants not yet taken up by water.

Another effect of filling in water from above is to wash off the plant, and to carry downwards, a certain quantity of dust and dirt, which, after passing through the strainers, will get mixed with the precipitated indigo in the oxidising vat, and never again be separated.

The advantages of filling from below are that the water level will rise steadily without there being any unnecessary commotion in the vat, no air need be carried into the vat by the inflowing water, and every portion of plant as soon as it is wetted will in the following instant be immersed. Also less dust will be washed off the plant, and a vat filled with water from below will contain less air in the shape of entangled bubbles after the vat is filled than a corresponding vat filled by a pipe from above.

The only case where it might be more expedient to fill in water from above than from below would be where the water supply used was itself muddy. In such case it would be folly, of course, to pour in muddy water at the bottom, whereas by letting it in at the top, the upper layer of the plant may act as a strainer, or inferior kind of filter, for the water, and the liquor which ultimately drains off to the oxidising vat may be less muddy than the water originally let on to the plant.

Really there is no excuse for ever using muddy water for factory purposes, in view of the facility with which dirty water can be filtered through sand, and in every case where clear water is used it is best to fill your vats with water by letting the water flow in quietly but quickly at the bottom.

Experiments to Illustrate Chapter II.

Water.

(1) Take a few small lumps of freshly burnt quicklime (pure if possible), slake these lumps with a little water, and so soon as they are slaked, put into three or four clean wine bottles, sufficient to cover the bottom of each about an inch in depth.

Then fill up the bottles with clear, soft water, cork them, shake them well for a short time, and set on one side till the next day, then pour off the upper layer of liquor from one of these bottles, and if the poured-off liquor is not quite clear, filter it though filter paper (or blotting paper), so as to get a perfectly clear, colourless liquid. This liquid will then be ordinary lime water.

Take some of this clear lime-water, say a wineglassful, and add to half a peg-glassful of clear, soft water. (Note.—Since pure soft water is difficult to obtain, and nearly all ordinary drinking water contains a little lime and carbonic acid gas, it is best for this set of experiments to use pure distilled water.) The liquid should still remain perfectly clear if the water contained no carbonic acid gas. (Note.—Oxalic acid and its salts would give a precipitate, but this acid is never found as an impurity in ordinary natural water.) Now pass into the peg-glass a stream of carbonic acid gas, when you will see that the liquid immediately begins to get milky, and in a short time it will be milky throughout.

This milkiness is due to the precipitation of the lime as carbonate of lime (chalk) by the inflowing carbonic acid gas.

Continue passing the gas, and after a short time you will see that the liquid commences to clear again, and at last it will end up by being perfectly clear and bright, as at starting.

This subsequent clearing of the liquid is due to the fact that the carbonate of lime is soluble in water containing an excess of carbonic acid gas.

If you have no suitable apparatus at hand for preparing carbonic acid gas, and for passing a stream of it through the liquid in the peg-glass, you can obtain precisely the same result with a little trouble by steadily blowing through a hollow reed, or, better still, through a small piece of glass tube, into the liquid.

The breath contains a considerable quantity of carbonic acid gas, and you will be able to precipitate the lime as carbonate, and to charge the water ultimately with sufficient excess of carbonic acid gas to re-dissolve it again by simply going on blowing a steady stream of bubbles through the liquid.

Now test this last liquid by adding to a little of it a clear solution of soap, and shaking it. You will see that the soap will curdle, the curds being similar to those obtained with ordinary hard water. Make a considerable quantity more of a similar liquor by mixing more clear lime water with a large volume of water in a jug or basin, and set a coolie to go on blowing through it until the liquid becomes clear.

Try the effect on your hands by putting a little of this liquid into a washing basin, and trying, then, to wash with it and with ordinary soap.

You will find that it will act just like hard water, it will feel hard and harsh to your skin, and the soap will go to curds, and you will find the greatest difficulty in cleaning your hands with this liquor and soap.

Now take some more of this liquor and fill a peg-glass about one-half full with it. Then drop gently and continuously into this a few drops of your clear lime water.

You will see that this will immediately make the liquid milky again.

Go on adding lime water continuously, drop by drop, until another drop added ceases to turn the liquid milky at the place where it enters. Let the glass containing this milky liquid stand at rest for a time sufficient to enable the sediment to subside, and the upper layer to get clear. Draw off then a few drops of this clear liquid and test first with a drop of lime water to ascertain if sufficient had really been added to the bulk of the liquor. If it gives a precipitate, then more must be added to the bulk gradually and cautiously, until the addition of an extra drop appears to give no further milkiness.

If, on the other hand, lime water does not give a milkiness with the few drops of clear liquor drawn off, then take another few drops of the same liquor, and test with a little solution of artificially made hard water (that is, your solution containing carbonate of lime dissolved in water containing excess of carbonic acid gas), to ascertain if lime water had been added in excess. If this hard water produces no precipitate, then just the correct quantity of lime water had been added to the hard water in the peg-glass to soften that water. If, however, the hard water gives a milkiness, then you know that an excess of lime water had been used, and more hard water should be added drop by drop cautiously to the bulk of the liquor in the peg-glass, until a further addition ceases to give a precipitate.

If these experiments are carefully performed, you will at last obtain a solution which neither precipitates lime water nor your artificially prepared hard water. When this result has been obtained, filter through filter-paper, and test the water again with soap, and you will find it is soft ; the soap will not curdle, and you can wash with it.

All this group of experiments will be found to be easy of performance, except the exact neutralisation of the hard water by the lime water. On a fairly large scale this is also very easy, and the difficulty of obtaining exact neutralisation increases with the smallness of the quantity you are working with, so that, instead of a peg-glass, it would be better to use a large glass holding a gallon or more, if such a glass is available. A peg-glass has been taken here because it is ordinarily the largest vessel of clear glass which is certain to be ready to hand; but a drop too much or too little of either liquor in half a peg-glass is relatively more than a gallon too much or too little in an ordinary reservoir tank.

For laboratory purposes, when it is desired to test the hardness of water, and to ascertain how much lime water should be poured into the reservoir to soften its contents, it will be found well to work with not less than a gallon of the water, or even larger quantities may be tested. This also must be considered—that if your water, to start with, was hard from containing carbonate of lime held in solution by excess of carbonic acid gas, then even a partial precipitation with lime water will produce a partial softening of the water, and so improve its quality for factory purposes; but, of course, the nearest possible approach to complete precipitation should be sought for where this result can be obtained without too much loss of time or trouble. In practice, the quality of the main supply of factory water will not vary largely from day to day (except after moderately heavy rain, when, by dilution with rain water, the average hardness of the supply will be diminished), and, having once ascertained, by careful experiment, how much lime water is required for the reservoir full of water, the operation of softening the water in the reservoir consists only in throwing into the reservoir a measured number of quarts or gallons of lime water—an operation which in itself need not occupy more than one man's time for a space of five to ten minutes in the day.

Lime water for factory use, for softening hard water, should always be saturated with lime, so as to be always of approximately the same strength. This result may be secured by always maintaining an excess of freshly slaked lime at the bottom of the small tank or vat in which the lime water is made. The cost of making the requisite quantities of lime water at a factory will be infinitesimal, and, when once the water supply has been satisfactorily examined, and its extremes of hardness ascertained, it would ordinarily be possible to construct an easy formula to regulate roughly the quantities of lime water which should be added to the reservoir from day to day.

It is important to remember always that it is better in practice to add too little than too much. Two little will do some good, and can do no possible harm ; too much will contaminate the water, and be injurious in the steeping vat.

(2) Make some more artificially prepared hard water as described above.

Take a couple of pounds of freshly-gathered leaves of the indigo plant, and divide into similar lots of one pound each. Pack each pound in a separate vessel, the two vessels to be similar in shape and size and substance, and after weighing each lot pour into one vessel sufficient distilled water to cover the plant, and into the other sufficient of the clear artificially-prepared hard water. Let both vessels stand over night for from 12 to 15 hours, and draw off or pour off the liquor from each into a separate vessel at the same time. Afterwards oxidise the liquors so obtained separately by similar means in similar vessels.

Observe that the fresh water has yielded the best results.

(3) Take a dessert-spoonful of plaster-of-Paris (sulphate of lime). Put it in a clean wine-bottle and fill with ordinary soft water, or better with distilled water; shake and set by to stand for twenty-four hours, then decant the upper layers of the liquor, and filter through filter-paper, if not quite clear, and observe that again you have hard water, but this water, unlike the hard water we made before, cannot be softened by adding lime water to it.

Try the addition of lime water to a little—there will be no precipitate formed.

Take another portion of the same solution, and add to it a solution of oxalate of ammonia. Observe that this gives a white precipitate. Go on adding oxalate of ammonia so long as each additional drop continues to yield a further precipitate. Add then a very slight excess of the oxalate, and filter. Observe that the filtrate is no longer hard, as was the unprecipitated liquor.

Test another small portion of your original solution with solution of chloride of barium. Observe the white precipitate formed, indicating presence of sulphuric acid in solution.

(4) Repeat Experiment 2, but, instead of employing water artificially hardened with calcium carbonate and carbonic acid gas, use some clear water hardened with sulphate of lime and compare results; as before, you will observe that the infusion with pure distilled water gives the best result.

(5) Compare, as in Experiments 2 and 4, the effects produced with indigo plant of the artificially hardened waters, and the same waters after they have been softened in the

one case by lime water and in the other case by oxalate of ammonia. Observe how the indigo extracting quality of the liquids has been improved by the processes of softening to which they have been subjected.

(6) Take a little stinking stagnant water from a pool and put it in a glass, add to this a small quantity of a fairly strong aqueous solution of potassium permanganate. Notice how the offensive odour disappears almost immediately, and the pink colour of the permanganate of potash is destroyed; go on adding potassium permanganate until the liquid retains a very faintly pink colour after standing some time; then filter, when you will find the filtrate to be free from the offensive organic matter, and on the filter paper there will be left a brown more or less slimy deposit, composed for the most part of organic particles stained with binoxide of manganese.

CHAPTER III.

THE OXIDISING VAT.

When the plant has been steeped in water for a sufficient length of time in the steeping vats, the liquor is then drawn off through valves provided with strainers, and allowed to flow into a vat or vats at a slightly lower level than the steeping vats.

The valves are at the bottom of the steeping vats, so as to allow all the free liquor to escape through them, and the strainers serve to prevent loose leaves or fragments of vegetable tissue from finding their way to the oxidising vats.

As most large factories are now constructed, the whole series of steeping vats on one side of a factory are commonly allowed to drain into one large shallow vat, which is often spoken of as the beating range.

It is a common practice in modern factories to construct two rows of steeping vats and two beating ranges: one row of steeping vats and a beating range being on one side of the factory, and a corresponding row and beating range on the other side; the series of vats being constructed close side by side, with only partition walls of masonry between them. A line running through the centres of a series of steeping vats would be parallel to the long axis of the factory, and the beating range is between the steeping series and the factory, with its long axis also parallel to the long axis of the factory.

This is the most convenient arrangement hitherto devised, both in construction and in working.

The steeping vats before referred to in Chapter I. are simply square pucca tanks, more or less deep, but always deeper than the oxidising vats or beating ranges.

Except the valves which lead out of them, and the channels through which water is conveyed into them, there is nothing special to note about the structure of a steeping vat, except, perhaps, that it may sometimes be provided with a kind of groove at the bottom, directed towards the valves to assist the liquor to flow off, and the base of the tank may have a slight incline inwards towards the oxidising vat, also with the purpose of assisting the draining off of all the liquor as far as possible.

It is essential, of course, that in no case should the base of a steeping vat have an incline in the opposite direction (*i.e.*, away from the valve), otherwise there will be loss of liquor, and hence loss of indigo at every steeping.

The old-fashioned oxidising vat in which the indigo was oxidised by hand beating, differed very little indeed in construction from an ordinary steeping vat, except that it had a relatively larger surface area, and was accordingly filled with liquor to a less depth; but a modern beating range, in which the oxidation is accomplished by beating with machine paddles driven by a steam-engine, is not quite so simple in construction.

A beating range consists, essentially, of one large pucca tank, many times longer than it is broad, and having a much larger superficial area than the sum total of the superficial areas of all the steeping vats which feed it.

The base of the vat which constitutes the beating range is commonly constructed with a slight incline inwards, *i.e.*, away from the steeping vats and *towards the factory side. Also there is sometimes* a very slight incline towards one end of the range, generally towards that end nearest to which the paddles are placed.

The nearer edge of the range may or may not be provided with a shallow gutter, but in every instance there is a well at one corner of the range on the side nearest the factory, and the inclines above referred to dip towards the well. The combined effect of a slope to a side and a slope to an end will be a slope to a corner, and that corner must be the corner in which the well is placed.

The well at the corner must be sufficiently capacious to hold easily the whole of the indigo deposit which can be obtained from a full supply of good plant in all the steeping vats which open into the range.

There are also a pair of shallow pucca walls which spring from the base of the range, and run parallel to the long axis of the vat, the walls being arranged at equal distances on either side of the long axis, so as to divide the base of the range into three longitudinal channels—one centre channel and two side channels.

These walls must not reach to the ends of the range. They serve to bound a channel up the centre of the range, but they admit of free communication between the central and side channels at both ends of the range.

These walls are provided with valves at regular intervals throughout their length in the best constructed ranges, the valves, when open, affording communication between the channels on either side of the walls.

The beating range is also provided with certain openings for letting in and letting out its contents. The only openings into the range are the valves from the steeping vats before referred to. These valves are usually placed at regular intervals along the outer long wall of the range. They correspond, of course, to the position of the steeping vats.

The openings out of the beating range are two in number—one for draining off the waste liquor from which indigo blue has been precipitated and subsided, and the other for drawing off the precipitated indigo for subsequent treatment inside the factory walls.

Both these openings are at that corner of the range where the well is, the drainage opening being about level with the top of the well, and the indigo opening leading from the bottom of the well. The lower opening for the indigo is controlled by a valve, or plug.

The upper, or drainage opening, is in immediate communication, on the side towards the tank, with a drainer which can be depressed at will, so as always to drain off the surface liquid only. The exact shape of the drainer it is not very easy to describe in words, but a fair idea of it will be obtained if you imagine a hollow truncated cone, squashed in sideways near its base, so that, instead of a circular cross section it shall at its base have a cross section like a broad slit with rounded corners. This slit-like opening is arranged horizontally, and, when the lower edge of the slit is depressed below the surface, the surface liquor runs into the distorted cone and out by the circular opening at the other end, which communicates with a drain outside the range. You only have to imagine this apparatus movable about a pivot at the end towards the outside drain, so that the broad slit end can be raised and depressed at will, and you will understand the principle of the drainer, and how the drainage opening is controlled.

The above is a fairly complete description of an ordinary beating range, so far as the beating-range vat and its outlets and inlets are concerned.

The apparatus for beating consists of a series of paddles, radiating from an axle, like the spokes of a wheel. The terminal paddles, or blades, are very small rectangular plates, and the spokes which carry them are strong and very firmly connected with the axle. The direction of the axle carrying the paddles is at right angles to the length of the beating range, and extends into the factory, where is ordinarily placed the machinery for revolving the axle and so driving the paddles. Commonly, this main axle is in the same straight line with the corresponding axle connected with the corresponding paddles for the beating range on the opposite side of the factory, and the axles of both sets of paddles can be connected by a simple mechanical appliance by which the factory ends of both axles are so firmly interlocked that the whole will revolve as one axle; or, when desired, they can be disconnected, and the set of paddles on either side of the factory worked independently of the other set by separate driving gear attached to each separate axle. The paddle arrangement is much nearer to one end of the vat than the other, the end to which it is nearest being the deeper end, at the inner corner of which is the well before described.

The portion of the vat in which the paddles work is inside (*i.e.*, between) the two walls which bound laterally the channel up the centre of the vat before referred to, and not far from the proximal ends of those walls. The paddles, in revolving, dip very nearly to the bottom of the vat.

The paddle facets, when they dip into the vat, face forwards in the direction of the length of the vat; and, when the axles are set revolving so as to drive the paddles, they drive the liquor in the vat before them between the two longitudinal walls towards the far end of the vat, where, escaping from the confinement of the walls (which, as before stated, do not reach to either end of the vat), the liquor finds its way into the side channels, and thus back again to the near end, where again it is drawn inwards to replace the liquor being driven forwards by the revolving paddles, so that the whole liquor in the vat is being kept in continual circulation up the middle and down the sides, and again up the middle, and so on, all portions of the liquor in the vat thus passing in turn again and again through the area where the paddles are at work.

The theory of the beating vat or range is exceedingly simple. When indigo plant has been steeped long enough and the liquor drawn off, that liquor contains *something which absorbs oxygen gas freely from the* atmosphere when it is brought into contact with it, and the absorption of the oxygen gas causes a precipitation of indigo blue. These are facts capable of easy experimental demonstration, and independent of any theory as to what may be the particular substance in the plant which yields the indigo blue on oxidation.

If a little of the liquor as it flows from the steeping vat be put in a soup plate and left to stand quietly in the air, indigo will after a time precipitate, but the time will be much longer than it will be if you take two soup plates, one empty and the other full, and keep on pouring from one into the other; or, if by any other means you promote fuller contact between the liquid and air, by bringing larger surfaces into contact with fresh supplies of air, as, for example, by blowing air into it, or by shaking it up in a succession of bottles, with continual fresh supplies of air, or by beating it with a fork, or by saturating white cloth with the liquor, and working the cloth about in the air, or by any other method which may be desired for promoting contact over large surfaces.

On the other hand, if you were to take some of the fresh-drawn liquor as it leaves the steeping vat, and immediately transfer it to a bottle, with a moderately thick layer of fresh sweet oil to cover it and to exclude all air, and if you were to cork this up tightly and stand it on one side, no indigo would precipitate, even after standing for days.

The beating vat is simply an oxidising vat. Formerly the old-fashioned primitive method employed was to send a lot of men into the vat with wooden paddles to scoop up the liquid, and to toss it into the air, when it would fall back into the vat. The liquid thus tossed up would expose a relatively large surface to the air above the vat, and on falling back into the vat would carry a quantity of air in with it. The beating paddles are merely a mechanical arrangement for doing by machinery what was previously done by hand. The vat is shallow and of large superficial area, so as to expose a large surface to the atmosphere, and the paddles cast up quantities of liquor in the form of spray and beat in air, and so hasten oxidation, which would be a much more tardy process if the liquor were left to rest without disturbance.

The partition walls rising from the base of the beating range serve only to regulate the circulation of the liquor, so that all parts may in turn be equally paddled; and the paddles themselves, besides splashing up the liquid and generally causing a great commotion at and near the surface, drive the current forward, and so create the circulation which the partition walls control.

As with the steeping process so with the beating process—there is no fixed limit of time during which the beating should be continued. The beating process is always a much shorter process than the ordinary steeping process, but it may last several hours before it is completed. Usually during the early stages of the beating process a high head of froth is formed, white at first, but gradually turning blue, as it circulates slowly up the centre and down the sides of the beating range. As this oxidised froth comes back again under the paddles, the oxidised indigo gets beaten into the liquid in great part, and fresh white or pale blue or greenish blue froth is formed, but little by little the frothiness becomes less; and as with the steeping vat the time when the head of froth began to subside would ordinarily be an index that the vat was ready to draw, so in the beating range a cleansing of the surface of froth will generally indicate that the process of oxidation is approaching completion.

At this time the practice is to examine a little of the liquor, taken from near the bottom as much as possible, to see if the indigo deposit which has formed has commenced to granulate. It will be remembered that the fresh-drawn liquor from the steeping vat would ordinarily be yellow or orange, or, with long steeping, greenish yellow. This colour rapidly changes through shades of green to blue in the early stages of beating, and for a time the liquid has a more or less muddy appearance from the presence of exceedingly minute invisible particles of partially oxidised indigo; but later on the indigo manifests a disposition to granulate, and collect into a number of small blue specks, or *fæculæ*, as they are called.

When this condition is reached, the indigo will subside most easily to the bottom of the vat, and it is the practice then to stop the beating and leave the indigo to subside quietly.

If beating is continued for too long after the indigo has commenced to granulate, the granules may again get broken up into impalpable particles, which will get disseminated through the whole mass of liquor, and subside only with great difficulty afterwards. Besides, when the stage of granulation is reached, the oxidation, if not quite complete, will be so near completion that, during the two, three, or four hours while the liquid is left quietly at rest after the paddles are stopped, any small quantities of indigo which might have escaped oxidation during the beating, will have abundant time to absorb from the air the little oxygen still required, and will subside with the *fæculæ* and increase their size and consistence.

The time which will be required for the beating process will depend upon a number of circumstances, as, for example, the depth of liquor and surface area of the vat—with deep layers of liquor, the time being longer, and with large surface, shorter; also upon the temperature and the state of the weather, and upon whether the air above is still or a breeze blowing, or whether the sun shines on the vat or not. Generally it may be said that a warm temperature and free circulation of air above the surface of the liquor in the vat promote rapid oxidation.

Direct sunshine on the vat seems to have the same general effect of shortening the oxidising period, though sunlight is by no means necessary for the oxidation, and I am disposed to think that the sun's rays act chiefly by warming the vat and promoting convection currents.

The beating period may also be affected by the length of the time during which the plant has been steeped. When the plant has been oversteeped, oxidation will have already commenced in the steeping vats at and near the surface of each, and ordinarily the beating period will be somewhat shortened; on the other hand, the liquor from understeeped plant will require full time for oxidation, but it will give better *fæculæ*, and purer and better indigo than oversteeped plant.

If the plant has been much oversteeped, and especially if the water used for steeping was highly charged with organic matter before being let into the steeping vats, it may happen that good *fæculæ* cannot be obtained in any quantity, and the indigo may refuse to altogether subside in the oxidising vat. When this happens, the reason probably is that the liquor teems with animalcules (visible only under the microscope), and these little transparent gelatinous animalcules will have eaten the indigo, or a good part of it. The indigo thus eaten will still show through the walls of their bodies of an inferior blue colour, but living organisms prefer to swim about and enjoy themselves in a suitable medium, and they won't sink unless they are paralysed or killed.

Hence the liquid will retain a blue or green colour, and only the uneaten indigo with any dead bodies there may be will fall to the bottom, and the indigo will have a slimy, sloppy character, and be very difficult afterwards to drain on the tables or to press, and will eventually yield bad cakes of inferior colour which will almost certainly crack on drying.

Probably when the beating process is continued for much too long a time something of the same kind happens. The *fæculæ* which have first formed, and which, if left to themselves would have fallen quietly to the bottom, get stirred up again and again by the paddles, and are so brought continually near the surface where animalcules mostly congregate, and then they get partially eaten.

Animalcules, like larger animals, require light and air, and they crowd towards the surface, so that indigo which has formed and sunk to the bottom is relatively safe there, but not when it has been stirred up again. Each successive stirring up results in a certain quantity not falling down again, because it has been eaten.

Sometimes, when indigo will not granulate, either because it would not go down satisfactorily in the first instance, or because the *fæculæ* appear to have been in great part destroyed as a result of beating too long continued, a watery solution of an astringent gum (dhak) is sprinkled over the surface of the vat, after which the *fæculæ* make their appearance as they should have done without this adventitious aid. The *modus operandi* of this gum I have not had time or opportunity to study, and can only suggest, as a probable explanation, that it may act by killing the animalcules, or the tannin in the gum may act as a direct precipitant of some glucoside or other neutral principle existing in the infusion of the plant in small quantities, and so create nuclei for the agglomeration of the indigo particles. Further investigation in the laboratory, with the aid of a good microscope, may, perhaps, throw light upon this subject and make that certain which is now mere matter of speculation.

In any event, it is a fact that dhak gum will cause indigo to granulate which would not granulate when left to itself, but the quality of the indigo thus obtained is inferior to that of indigo obtained in the usual way.

The length of time which will be required for the indigo to subside in the beating vat after the beating is stopped will vary very much with the nature of the *fæculæ*. When the *fæculæ* are good, the subsidence will go on very quickly, and, as soon as the upper layers of the liquor in the vat appear to be free of indigo particles, the process of draining off the surface water may be commenced.

This process consists simply in depressing the lower edge of the slit-like orifice of the drainer below the surface layer of the liquor, the slit-like orifice being gradually depressed more and more as the surface level falls, until all the liquor has drained from the vat, and only the well remains more or less full.

Formerly oxidising vats were drained by removing one after another of a series of plugs arranged one above the other at different heights in the vat; but, just as the machine paddles are a decided mechanical improvement on the old hand paddles, so the drainer of modern construction is a very decided improvement on the old-fashioned primitive clumsy arrangement of plugs. But, as in the former case, so in the case of the modern drainer, there has been no change in principle, only a mechanical improvement in the method. It will be readily understood that the slight incline of the base of the vat towards the well at the corner where the drainer is will favour the draining off of nearly all the liquor from which the indigo blue has subsided, and the numerous valves in the longitudinal walls before referred to will, when opened, establish free communication between the side channels and the central channel, so that the operation of draining all the deposited indigo towards the well at the corner, and the subsequent operation of cleaning out the whole vat will be facilitated by the existence of these valves in the walls.

For driving the deposited indigo to the well in the corner, various methods may be employed. A hose-pipe fitted with a nozzle so as to deliver a flattened jet of pure water on the base of the vat can be worked by hand, so as gradually to sweep all the indigo towards the well, the hose being made to play in the first instance at the far end of the vat. This method employed *per se* has the disadvantage of introducing a considerable quantity of water into the vat, which has again to be got rid of afterwards; but, on the other hand, as the water introduced is plain, clean water, it will not contaminate the indigo with any impurity, and it will act as wash-water for the indigo. In practice it is not found convenient to introduce into the beating range any large volume of water for washing the indigo towards the corner, because the indigo thus stirred up again with water would not readily subside, and, unless the well is unusually large, it would not all, or nearly all, be able to find room there; and, even if the well valve were opened at an early stage while the vat was being swilled out, the total volume of liquor which would then have to pass through to the reservoir (to be referred to in next chapter) would be inconveniently large in proportion to the quantity of indigo it would contain.

Another method of driving the precipitated indigo towards the corner well, is to sweep the bottom of the vat, commencing from the far end, with india-rubber scrapers, each with a square straight edge below. By this means nearly the whole of the indigo slime or paste can be driven to the well, and the rubber, which can make a fairly clean sweep of a good smooth pucca bottom surface, is not sufficiently hard to injure the substance of the vat lining. When the bulk of the indigo has been driven to the well by this means, the base of the vat, and especially the valve apertures, can then be rinsed with a very small quantity of water, and the same rubber scrapers can be once more used to drive the rinsings towards the corner.

I have seen common hand brooms, such as sweepers use, made of bundles of twigs tied together, used for the purpose of driving the deposited indigo to the well; but this plan is very primitive and clumsy, and results in contaminating the indigo to some extent with dirt.

The twigs themselves are more or less abraded in the process of sweeping, and thus yield tiny particles of vegetable impurity; and brooms of this description are more injurious to the lining surface of the base of the vat than a smooth, clean edge of rubber.

The next thing to be done, after the indigo has been collected in and about the well, is to draw it off from there. For this purpose a valve at the lower part of the well wall is opened, and the indigo and water, of about the consistence of cream, is allowed to flow along a suitable channel, which leads inside the factory building, where it is strained and collected in a special reservoir or tank, or it may be introduced directly after straining into a boiler.

The operations inside the factory will form the subjects for consideration in the next chapter. So far, then, we have considered in this chapter the ordinary methods in common use for oxidising indigo, and with slight modifications in matters of detail, the foregoing descriptions would apply to a very large proportion of existing factories.

Now let us go on to consider whether it is not possible to improve on the principle of the beating range, and, if so, how improvements can best be effected.

We have seen that to obtain indigo blue from the liquor which is drawn off from the steeping vats, nothing more is necessary than to promote free contact between that liquor and atmospheric air, when the free oxygen of the air is absorbed and blue indigo precipitated.

The practical problem to be solved is simply, therefore, how best to promote the fullest possible contact between all parts of the liquor and large supplies of fresh air.

The old-fashioned plan of tossing the liquor up into the air was a simple and fairly effective means of promoting extensive contact. The portion of liquid thrown up would spread out in the upper air as sheets and spray, which would expose a relatively large surface to air, which would be continually in process of renewal by air currents and gaseous diffusion, and the liquor on falling back into the vat would carry in with it a certain quantity of air from near the surface, this air escaping finally in the form of bubbles, after having first parted with some at least of its oxygen to the indigo.

This method was fairly efficient, but subject to several serious drawbacks, the chief of which were (first), that the process was unhealthy for the men engaged for tossing the indigo liquor; (second), the labour was costly; (third), it was intermittent and irregular, and constant supervision was required to keep the men up to their work.

These objections have all been overcome to a large extent by the simple process of beating by paddles driven by steam.

The old process would more appropriately have been called tossing than beating. If the modern steam-driven paddles were so constructed as to do more vertical tossing and less beating than they do, they would be more efficient than they are.

Beating, *per se*, is useless waste of power. Nothing whatever is gained by a series of violent concussions between solid paddles and the indigo liquor.

The oxidation of the indigo depends solely upon—

(1) The surface area of the vat.

(2) The surface area of the portion of liquor tossed up into the air above.

(3) The surface area of the air driven into the liquor.

(4) The internal currents in the liquor, which result in continually bringing fresh quantities near the dividing surface of air and liquid.

Revolving paddles do toss up liquor into the air in the form of spray; they do carry down into the liquid a certain quantity of the air, and they do keep up a circulation in the fluid as before described; but, besides all this, they do a lot of actual beating, and they develop a fair amount of useless concussion, and equally useless friction, where the solid and liquid surfaces come into contact. Hence, although steam-driven revolving paddles are less costly to work with than coolie labour, yet they are wasteful and extravagant, and the machinery for driving these paddles is costly to purchase, and liable occasionally to get out of repair.

Paddles of one kind or another have been used for so long in indigo manufacture that they have come to be generally regarded as the accepted if not the only satisfactory means of oxidising indigo; but in reality there are other modes of oxidising, which are simpler, quicker, and less costly, both in construction and work.

One very simple method is to pump the liquor from the oxidising vat into an overhead reservoir in communication with a number of finely divided fountain jets in the oxidising vat, the fountains to be kept playing until the whole liquor is oxidised.

Another very simple method is to pump the liquor to an overhead vat, whence it can be allowed to escape slowly over the surface of a long, gently inclined plane, provided with numerous pegs or other projections or irregularities to divide up the descending liquor as it trickles down.

Another plan is to collect the liquor in a moderately deep vat, and to go on steadily pumping in air at the bottom, so as to keep the whole in a state of ebullition until the oxidation is complete, or, if preferred, air can be introduced below by suction produced by a steam jet.

All these methods are fairly simple and economical in construction and in operation, and the first and last named of these methods will be found to be more expeditious than the steam paddle method; but by far the best method yet devised for oxidising indigo is to pump the liquor from the oxidising vat into an overhead reservoir, whence run a series of gutters over the oxidising vat.

These gutters should all be provided with tubes, and every one of these tubes should be terminated by a finely perforated metal head such as is used for an ordinary garden watering-pot or for a shower-bath.

These gutters, with their exit tubes and shower heads, should be so arranged over and round the oxidising vat that, during the whole time while the liquor is being pumped up from the vat into the overhead reservoir, the liquor shall be flowing from that reservoir through the gutters and exit tubes and shower heads, so as to keep up a continuous rain over the whole surface of the bath.

By this method, the period required for oxidation may be reduced to half an hour or even less, and need never exceed an hour, even in the case of a fairly deep oxidising vat. Also this method is far more economical than the paddling method.

It will be seen at once that the construction of the small overhead reservoir gutters and spouts will be very much less costly than steam paddle machinery, and the cost of working an ordinary centrifugal pump by steam for from half an hour to an hour will be decidedly less than the cost of working the paddle machinery by steam for three or four times as long a period, and, further, the great saving of time is in itself an important consideration.

This method of oxidation of indigo by causing the liquor to traverse a considerable thickness of air in the form of rain over the whole surface of the vat is new, and I have recently obtained a patent for this invention under the Inventions and Designs Act of 1888.

The other methods above referred to I have tried, but an experimental investigation has shown that the method last above described is by far the most efficient of all the methods yet devised for indigo oxidation.

For some time I was in doubt whether a fountain arrangement might not be as good or better than a shower-bath arrangement, but I have now no longer any doubt upon that subject.

The advantages of the shower-bath method of oxidation are : (1) that no complicated or costly machinery is required to work it. An ordinary centrifugal pump and a steam-engine, such as nearly every factory possesses, will amply suffice, and the small overhead tank, gutter, tubes, and shower-bath heads can be easily constructed by any workman of fair ordinary intelligence.

(2) There is a minimum waste of power by this arrangement. The whole of the liquor which is raised by the centrifugal pump will have to pass in a state of very fine division through a layer of air of nearly the same depth as the vertical height through which the liquor has been raised by the pump.

(3) The fine jets of liquid which will be formed by passing through the perforations of the shower heads will, when they reach the surface of the liquid in the lower vat, penetrate to a considerable distance below

that surface, and carry down with them to near the bottom of the liquid a quantity of air bubbles, so that the whole surface of the vat will be maintained in continual ebullition.

The fountain method, which looked tempting, has some disadvantages as compared with the shower-bath method.

First and foremost among these comparative disadvantages is the fact that the fine jet fountains will not rise nearly so high as the reservoir which supplies them. Often, indeed, if the fountain jets are very finely divided, the height of the ascending jet will be only a small fraction of the vertical height of the reservoir, so that, although a fountain arrangement would cause the liquor to be exposed to air in a fine state of sub-division, both in ascending and in descending, yet twice the height of the fountain jet (if very fine) would not ordinarily equal the height of a rainfall from the level of the base of the same reservoir, and to set off against the fact that the watery particles of a fountain jet would ordinarily be exposed for a somewhat longer time to the air before again reaching the vat is the very important consideration that, with the same overhead reservoir, the vertical height of the column of air which could operate upon the fountain jet to oxidise it would be half, or less than half, that which would act upon the rain.

Also the fountain spray in falling back into the vat would have a much less accelerated velocity and carry in very much less air to oxidise the mass of liquor in the vat.

Also, fountains rising from the base of the vat would be in the way. The tubes to feed fountains could not be conveniently led along above the surface of the base of the vat, and to put them under the surface would necessitate a breaking up of the whole surface of the vat, and relining it with pucca plaster.

This arrangement would be highly inconvenient if the pipes were at any time to get choked, as they might easily do, and the fountain jets themselves would be very liable to get choked up. Also, for fountains a greater length of metal tubing would be required, and this would mean cost and loss of power by internal friction. Whereas, with the overhead arrangement of shower-bath heads, such as I propose, the heads can easily be made so as to slip on to the tubes, so that they and the tubes and gutters can quite easily be cleaned at any time; they will always be in come-at-able positions, and they will be less likely to get choked than fountain tubes or fountain jets.

Altogether the balance of advantage and disadvantage works out strongly in favour of my shower arrangement for oxidation.

The method of oxidation by pumping in air or by sucking it in by means of a jet of steam is altogether inferior, and by comparison very wasteful of power.

It will work, of course, and, if air is driven or sucked into the lower layers of liquid in a vat in sufficiently copious quantities, the process of oxidation may be got over quickly; but the quantity of fuel consumed in working this process will be very largely in excess of the quantity consumed in my method. Any student of elementary hydrostatics will see the reason for this at once.

As much power is consumed in driving air under water as in lifting water up in the air, and, with the consumption of a given amount of power, the total surfaces of air and water brought into contact will be very much less.

Experiments to Illustrate Chapter III.

(1) Take a piece of white woollen cloth or flannel, wring it out well with clean warm water. Dip this cloth into the liquor which has just been drawn off from the steeping vat, and hang it up in a current of air. Repeat the dipping several times at short intervals, and after each dipping expose freely on a line to the air.

The cloth will be dyed with indigo blue, just as it would be dyed in an indigo vat. Exposure to the air will have precipitated indigo blue on the fibre of the cloth.

(2) Take some of the fresh-drawn liquor and transfer it to a clean deep bowl. Take some more of the same liquor and put it in a clean shallow dish. Then set the bowl and dish on one side where they will not be disturbed, and watch them at intervals. Note that an indigo film will form on the surface of each lot of liquid. After a few hours have elapsed, draw off a very small quantity of liquor from near the bottom of each vessel, transfer to two clean white saucers or plates.

You will find that long after all the dye had precipitated out of the solution in the shallow dish, the precipitation of the dye from the deepest layers of the liquid in the deep bowl will not be complete. This fact can be verified either as above suggested, by transfer of corresponding small quantities to shallow plates, or by wetting two similar pieces of flannel with the liquor, and exposing them to air, or by rapidly filtering both liquors through filter paper, and afterwards leaving them to stand, when the liquid from the bowl will yield a further crop of indigo blue after standing, while the liquor from the shallow dish should, if the time has been well chosen, *yield no further precipitation.*

(3) Take some of the clear fresh-drawn liquor as it emerges from the steeping vat, and fill a tall peg-glass with it. Stand this on one side, where it will not be disturbed, but can be watched. Note that an indigo film will form on this surface after a time, as in the last experiment; and note also how the layer near the surface will *gradually acquire a green colour*, which deepens, as time goes on, from precipitation of indigo particles near the surface. Note also how the bluish-green colour gradually penetrates downwards into the liquor, the lower portions remaining yellow long after the upper layers have passed to bluish green. The green tint is, of course, due to the fact that the blue indigo is seen through a yellow liquid.

(4) Take two equal portions of liquor fresh drawn from the steeping vat, and put into two similar vessels. Set one of these vessels aside, where it will not be disturbed, and oxidise the other by continually ladling it up with a spoon, and letting it fall back into its own vessel from a moderate height. Observe how much sooner the indigo blue is precipitated from this liquor so treated than from the other corresponding lot, which has been simply left to stand without disturbance.

(5) Again, take two corresponding equal portions of fresh-drawn liquor in similar vessels. Set one vessel on

one side, as before, and blow air through the other by attaching an indiarubber tube to the nozzle of a small pair of bellows. The end of this tube may then be led to the bottom of one of the vessels, and air blown in; or, better, the tube may be fitted with a fine short glass tube to act as nozzle, and a steady stream of air blown through the liquid.

Observe how long it takes to oxidise the whole of the liquor. Observe also, with reference to observations towards the end of Chapter III., how relatively large are the bubbles of air compared with the cross section of the blow tube.

Observe that the indigo precipitates much more quickly from this liquor than from the undisturbed lot.

Note also that all these experiments show that free exposure of the liquor to air, by whatever means the free exposure is produced, will always hasten oxidation.

(6) To establish this generalisation more fully, take, as before, two fresh-drawn equal portions of liquor. Put in two similar deep vessels. Cover the liquor in one of these vessels with a layer of an inch of sweet salad oil, and leave the other uncovered as in all former experiments. Let both vessels then stand by for twelve or fifteen hours or more. Note that the indigo blue will have precipitated from the exposed liquor, and will not have precipitated from the oil-covered liquor.

(7) Fill a deep glass vessel three-quarters full of bright clear water; a deep glass water-jug will answer well, or, if that is not available, then a deep peg-glass will do. Take also an ordinary glass syringe with a fine nozzle, and, having filled the syringe with clear water, squirt this water vertically downwards into the water in your deep vessel. The nozzle of the syringe should be at some height above the surface of the liquid when the piston rod is forced downwards.

Observe how the fine jet of water on penetrating the liquid in the vessel will carry in with it to a considerable depth quantities of air bubbles.

Next, instead of using a syringe at a small height, take a tin can or other vessel with a tiny hole in the bottom of it. Fill this with water, and hold it over your deep glass vessel already containing water, so that the tiny jet of water which is issuing from the minute perforation may fall into the water in the lower vessel.

Observe that air bubbles will be carried down into the liquor in the glass vessel by the falling jet. Raise your perforated can gradually to a greater height and note the difference in the depth to which the air bubbles will penetrate the liquid in the transparent glass vessel.

(8) Fit up a shower-bath arrangement at a height of six to eight feet above a clean wooden bath-tub, taking care that all the jets from the shower bath overhead shall fall inside the tub when the shower bath is at work. Take care that the perforations are very minute, so as to give a fine shower, and test the arrangement with plain water, until you find you have a good shower of some few hundreds of jets, and the whole of the jets fall inside the tub. When all is ready, empty your shower bath, and throw away the water from the tub, and in its place put some few gallons of liquor fresh drawn from a steeping vat, after the proper amount of steeping has taken place.

You may thus fill your tub one-third or one-half full, say one foot to one and half feet in depth.

Then set a servant to go on ladling up with a capacious vessel the tub's contents, and pouring them into the tank of the shower bath, which should be open and free to work continuously.

Keep this arrangement going for from half an hour to an hour, and observe how very rapidly the oxidation of the indigo proceeds. Observe how that, if the jets are sufficiently fine and numerous, and the ladling or pumping up is proceeded with continuously, the whole of the indigo in the tub may be oxidised in about half an hour, and the time of oxidation will never, even with liquor from understeeped plant, exceed an hour.

Repeat this experiment several times, with variations as regards the number of jets, the fineness of the perforation, the vertical height of the shower, the depth and volume of liquor in the tub to start with, &c., and satisfy yourself thoroughly as to the efficiency of the method.

(9) Compare the shower-bath method above referred to with scooping or tossing-up method, and with beating or other forms of agitation.

To do this, take a fair number of gallons of freshly drawn liquor, and divide into equal portions in different but similar tubs.

At one of these tubs set a man to toss up the liquor, while another tub is being oxidised by the shower-bath method, and a third, if you like, by beating, and a fourth, if you like, by blowing in air with bellows. One man should be set to each tub, and all should be encouraged to do their best to promote as rapid oxidation as possible, each by the allotted method.

At the end of from half to three-quarters of an hour, stop all at the same time, and test the liquors to see how oxidation has proceeded under each method. You will observe that the shower bath method of oxidation will have outstripped all the other methods you have tried, and the whole of the indigo will be oxidised by that method, while oxidation in the tossing or beating vats will not be half completed.

The man working the shower bath will doubtless get tired if he has to keep on lifting large quantities of the liquor to a height of six or eight feet; but, if you provide him with a hand-pump to pump up the liquor, his labour will not fatigue him much more than beating or tossing would have done for the same time, and the sum total of his labour for developing complete oxidation of his liquor will be less than the sum total of the labour of the other men, who, for complete oxidation, will have to work so much longer.

(10) Try the fountain method of oxidation, and observe the various facts referred to in the text of Chapter III. with reference to this method. To compare the fountain method with the shower-bath method the tubs should be similar, they should each contain the same quantities of liquor, and the reservoir for the fountain should be at the same height as the reservoir of the shower bath.

A tube should descend from the reservoir to below the level of the liquor in the tub, and, after leading upwards, should terminate with a rose head similar to the shower-bath head, but pointing upwards instead of downwards. The fineness of the perforations should be the same, and the number of holes should be the same. If the two methods are then set to work side by side, the advantages of the shower-bath method will become obvious at a glance, and the time occupied for oxidation by that method will be observed to be shorter than by the fountain method.

(11) Observe the effect of adding a few drops of aqueous solution of dhak gum to indigo liquor which won't yield good *fæculæ*.

Observe the dark brown-red colour of the gum, and the impoverished colour of the indigo if much dhak gum is added. Observe also that the liquors which will not readily allow suspended indigo to subside have for the most part a more or less offensive odour, and these liquors teem with organic life.

CHAPTER IV.

LATER STAGES OF MANUFACTURE.

AFTER the waste liquors of the oxidising vat have been drawn off, and the deposited indigo blue has been accumulated in and around the well under the drainer, a valve at the bottom of the well is opened, and the indigo led off in a thick stream to a reservoir inside the factory. Before it is allowed to enter that reservoir it is compelled to pass through strainers of coarse cloth, to separate off any particles of solid impurities of appreciable size which may by chance have got mixed with the indigo in the oxidising vat.

Next, the indigo is transferred to a large boiler, which is commonly fixed at a considerably higher level than the reservoir. The indigo is now commonly raised from the reservoir to the boiler by a very simple steam ejector arrangement; formerly pumps were used, and occasionally even the more primitive plan of hoisting up by hand labour.

After the indigo has been transferred to the boiler, it is then heated up to the boiling point. In modern days this heating is effected by a jet of steam led with a small separate boiler and a small separate table.

When the liquor which passes through the cloth is no longer charged with indigo particles, it is allowed to flow away out of the factory by suitably arranged drainers. After a variable number of hours, the time depending very much upon the state of the indigo when it first reached the table, the indigo will ordinarily subside more or less completely upon the cloth, and if everything has gone well up to that point, the indigo deposit on the cloth will have a consistency not very unlike the consistency of fine river mud which the stream has just left. At this stage a planter with experience can tell approximately how his indigo cakes will probably turn out.

Under the most favourable circumstances the indigo will readily subside upon the cloth, and yield a deposit of uniform consistency, which can be taken up in handfuls and will hold together in the hand, but under unfavourable conditions the indigo will remain sloppy and slimy.

This last-named condition of the indigo is always due to the presence of large quantities of organic matter, and sloppy indigo will almost invariably have an offensive smell.

The common causes which tend to produce this sloppy condition of the indigo on the table are over-prolonged steeping—over-prolonged exposure in the oxidising vat, or bad water supply, or two or all of these causes combined. When the indigo on the table has a sloppy condition, it is useless to hope that over-prolonged resting on the table will suffice to secure a good deposit. Previous over-prolonged exposure was probably, in a large majority of cases, the main cause of the existing sloppy condition, and there can, I think, be no doubt but that the more quickly the indigo can be extracted from the plant, collected, pressed, and cut up, the better will be the quality of the produce. The lower forms of organic life develop very quickly, and they increase and multiply with a rapidity which can only be appreciated by those persons who have had experience in observing with the aid of a microscope the changes which go on in vegetable infusions in a warm atmosphere.

The atmosphere is at all times charged with the germs of living organisms, animal and vegetable. Water always contains germs and living organisms, and the dust in the plant itself, when it is gathered, will consist in part of germs which are awaiting only the occurrence of favourable conditions to enable them to develop into active living forms.

If the plant can be steeped only for a short time, but under circumstances which will suffice to extract all, or nearly all, the contained indigo-forming materials—if, then, the liquor is at once drawn off and rapidly oxidised, and the indigo sediment quickly collected and made into cakes, the best quality product will be obtained; and, on the other hand, a prolongation of any one of the processes, or any unnecessary delay between two succeeding operations can be productive of nothing but mischief, chiefly as beforesaid, because with time the quantity of organic impurity will go on increasing in a progressive ratio, partly also because so long as indigo is exposed, either in the oxidising vat or on the tables, ordinary atmospheric dust will remain to contaminate the finished product.

To return now to the deposit on the table, the usual practice is to ladle or scoop up this deposit (after it has drained as fully as it appears to be able to drain), and to transfer it to presses. These presses are stout boxes, with numerous small perforations at regular intervals apart. The presses are lined with strong cloth (of jute or linen or cotton, or a mixture of two or more of these), with overlapping flaps. The indigo deposit from the table is poured into the cloth in the press box, and after a sufficient time has been allowed for it to settle down, the upper flaps of cloth are folded over, and the pressing slab is brought down upon it, and pressure gradually and steadily applied.

The best presses are worked by hydraulic pressure, but sometimes presses are worked by hand, in which cases the pressure is applied by means of a large screw, as in letterpress machines.

The effect of the pressure is to squeeze out most of the liquid which had not drained off from theindigo on the table.

It is essential that the pressing operation should be conducted by gradual, steady increase of pressure, otherwise the lining cloth will probably burst, and the indigo will be squirted out through the pressing cases, and also the indigo cake will not be uniformly dried, even if the cloth should not burst.

The object of the planter in employing the press is to obtain from it a good slab of indigo of uniform consistency throughout, and of such solidity that it can be conveniently handled and cut into small square cakes.

An indigo slab, when taken from the press, should have about the consistency of ordinary bar soap.

Indigo which has settled most readily upon the table will also settle most readily in the press, and will give the best slabs, and submit most quickly to the process of drying by pressure.

Sloppy indigo is more difficult to deal with, and with sloppy indigo an additional layer of coarse sack-cloth may be necessary in the press to prevent risk of loss from rupture of the ordinary cloth.

Whatever may be the condition of the indigo as it collects on the table, the planter cannot afford to throw it away, and he must make the best of what he has got, but he cannot expect to obtain cakes of indigo of the best quality from an inferior quality of "mal" (as the indigo deposit at this stage is commonly called), and the cakes ultimately obtainable from sloppy indigo will certainly contain organic matter in excess, and they will probably dry hard and brittle, and will have an inferior colour to the best indigo obtainable from good "mal."

When the presses are charged with the "mal" scooped from the table it is essential to put in at one time all which it may be intended to put for the construction of one slab. An experienced planter should be able to foretell from the appearance of the stuff which he has available for charging his press how much it will sink in the press under pressure, and he should fill up his press to a greater or less depth accordingly. Any attempt to add to the thickness of an indigo slab by putting a second charge of stuff into the press after pressure has been applied to a charge previously put in will certainly result in spoiling the indigo cakes obtainable from a slab so produced. The upper layer will not amalgamate with the lower layers, and the cakes obtained from such a composite slab, if they do not actually split in two along a plane corresponding to the division plane between the first and second charges, will certainly not be uniform in composition and appearance throughout, and the selling price of such indigo will be considerably less than the selling price of the cakes uniform throughout.

It is better to risk having some slabs a little thinner than the average standard thickness rather than to try to make up the proper thickness by fresh additions; but a careful man need never go far wrong if his presses have sufficient depth, and he observes carefully the consistency of the stuff he puts in, and regulates the depth to which he fills accordingly.

As above stated, the operation of pressing down the indigo to form a compact slab must be performed steadily and slowly.

The reason for this is that the indigo is not very freely pervious to water, and time is required for the liquor entangled in the interior of the mass to work its way through the interstices of the indigo particles to the outer layer in contact with the cloth lining of the press. Sloppy indigo especially takes a long while to press, because it offers a much greater resistence to the transit of liquid than indigo in good condition.

The reasons which made it advisable to get over all the previous stages of indigo manufacture as quickly as possible, do not apply to the pressing stage, because in the presses there is but little chance comparatively for organic growths to go on increasing, and there is no longer any chance of further contamination with dust or other impurity, and the advantage of proceeding with the pressing slowly and steadily is that by this means the whole mass will be most uniformly consolidated.

The pressing operations should not be stopped so long as any further application of pressure forces out more liquor through the holes of the presses, for the more the indigo is dried in press by pressure, the less liquor will there be left to dry away afterwards in the drying house by evaporation, and the less chance will there be of the cakes cracking.

When the pressing operation is completed and the indigo slab removed from the press, the slab should, without delay, be cut up into cakes. The slab should be cut up without delay, partly because it is more easy to cut up when taken fresh from the press, and partly because if allowed to remain too long in the draughts of the factory, it may shrink unevenly, or it may even crack.

For cutting the slab into square cakes a knife working on the guillotine principle may be used, or, better, the slab may be cut up by metal wires, the slab being first placed upon a specially constructed table, with longitudinal and tranverse slits the proper distance apart to serve as guides for the cutting wires.

When a slab has been cut up into cakes, those cakes should be stamped on the uppermost surface, *i.e.*, on a surface which formed part of the slab surface, with the factory mark, and a number to indicate the date of manufacture. The cakes should then be transferred to trays, and carried at once to the drying house, where they should be at once laid out on the shelves ready prepared for them.

A drying house is usually a building a short distance apart from the factory, and it consists ordinarily of a simple large room fitted with layer above layer of deep shelves which extend from near the floor to near the roof.

These shelves are commonly of trellis-work construction, and they are commonly covered with a layer of some kind of porous material, *i.e.*, with numerous tiny air-holes, such as chitai.

The cakes when taken to the drying house are laid regularly and at short distances apart, with their stamped faces uppermost, upon these shelves. The object of the whole arrangement is to provide room for storing a large supply of cakes, and to admit of their being so arranged that all six faces of every cake shall be equally exposed to the drying influence of a still atmosphere. Of course the faces which are next to the shelves will not be so freely exposed as the other surfaces. It is necessary, therefore, not to allow the cakes to rest too long on one surface, but to turn them over from time to time.

This operation of turning is especially necessary during the first few days, when it should be several times repeated. The turning should be of the topsy-turvy kind, so that the marked faces shall be alternately uppermost and lowermost; and to secure uniform drying for the other four faces of the cubes, each cube may be rotated through an angle of ninety degrees every time the cake is turned over.

It is important that the drying house should be so constructed that the indigo cakes on the shelves should not be liable to be exposed to draughts. A draught of air playing upon an indigo cake in the drying house will cause more rapid evaporation on the sides of the cake exposed to the draught than can occur in the far sides, and there will be unequal shrinking in consequence, sufficient in many cases to cause the cakes to split.

On the other hand, unless the air inside the drying house is being continually dehydrated by some desiccating substances, there should be ventilation, in order to allow fresh dry air from outside to replace gradually the air inside, which has gradually acquired moisture from the drying cakes.

Also the temperature inside the drying-house should be kept as nearly uniform as may be, and sudden changes of temperature must especially be avoided.

The shelves for supporting the indigo cakes in the drying-house, while the cakes are drying, are best constructed of wire gauze, stretched over or attached to appropriate supports of rods and wire.

The process of drying can be hastened somewhat, if from time to time heaps of freshly burnt lime (burnt kunker will do) are scattered on the floor of the drying chamber.

The fresh quicklime will absorb moisture from the atmosphere, and so, by drying the air, will promote more rapid evaporation from the exposed surfaces of the indigo cakes.

This action will proceed steadily and uniformly, so that, while the cakes will dry somewhat more quickly, the risk of cracking will not be sensibly, if at all, increased, provided always that no draughts are allowed to play through the houses. Generally there is plenty of time available for the cakes to dry before it is desirable to pack and despatch them to Calcutta for sale, and there is little or nothing to be gained by any attempt to force the final drying. All that is really necessary is that the cakes shall have reached the full degree of dryness which is obtainable in the place where the factory is situated before they are packed in cases, and weighed and sent to market. No indigo met with in the market is ever absolutely dry, but it should be so dry that the weight of a packed case at the factory, and the weight at Calcutta, and the weight after arrival in London shall be approximately uniform.

Absolute uniformity cannot be hoped for. Indigo cakes, like most other substances of a similar texture, are slightly hygroscopic, and they may even absorb moisture in small quantities after they have been dried, so that, on transfer from a dry to a moist climate, the weight of a parcel of indigo may increase slightly from absorbed moisture.

The converse of this is more commonly observed. Some factories are built in districts where the atmosphere is ordinarily very damp, as in Eastern Bengal, for instance. In such places cakes will not spontaneously dry to such an extent as they would in a dry climate like the Punjaub, or even in the N.W. Provinces or Oude or Tirhoot, and they may continue to lose weight when transferred to a drier atmosphere. The planter cannot avoid these consequences arising from atmospheric causes, unless he resorts to artificial desiccation and air-tight packing.

In practice, all that is done, or expected to be done, is to leave the cakes to dry as much as they will dry by spontaneous evaporation in the place where they are formed, and then to pack and despatch them without previously adopting any special method of artificial desiccation.

The cases in which indigo is finally packed for market should be made of well-seasoned wood, otherwise, apart from the risk of the wood splitting afterwards, and so exposing the contents to possible injury, the case itself will not preserve a constant weight, and small, though appreciable, errors will be introduced into the calculations of weight.

So far we have been considering in this chapter the steps ordinarily followed from the time when the indigo deposit was first collected in the well of the oxidising vat to the final drying of the cakes.

Probably most planters in charge of factories which aim at producing good indigo cakes of the orthodox kind, will consider that the boiler, tables, and presses are essentially necessary parts of a factory. A reservoir for receiving the indigo when it is first drawn off from the oxidising vat will not always be necessary when the main building lies at a very much lower level than the oxidising range.

In some such instances the indigo can be led from the well of the oxidising vat into the boiler after passing, of course, through strainers *en route*, but for this arrangement to work, the boiler in the factory must be at a lower level than the well of the oxidising vat, and the tables must be at a lower level than the base of the boiler, and there must still be sufficient depth below the level of the table to the drainage gutters provided for leading waste liquors away from the factory. In most situations it would not be at all convenient to construct the factory building with a floor at a very much lower level than the well of the oxidising vats, hence the necessity for a tank in the factory.

Now, let us consider whether the methods hereinbefore described in this chapter are not susceptible of improvement.

My belief is that the period which elapses between the time when the indigo first deposits in the oxidising vat, and the time when it is taken out of the press as a slab ready for cutting, is much longer than it need be. To a planter, loss of time in manufacture means loss of money, other things being equal, because a large part of factory labour during indigo manufacture is paid by time and not by quantity of produce worked off. Also, there can be no room whatever for doubt but that lengthy exposure of wet indigo to the atmosphere is injurious to the quality of the produce, because, during the whole time it is exposed in a moist condition in a warm atmosphere, organic growth will go on in the wet mass, and also exposure of large surfaces to the air will give occasion for the contamination of the indigo with dust, which is continually falling. Careless planters sometimes leave their indigo to stagnate for some short time in the well at the corner of the oxidising vat, and more often it is left to stagnate in the indigo tank before being transferred to the boiler.

Generally there is no excuse for this, and at all times, if the indigo is to be transferred to a boiler to be raised to boiling point, this should be done with the least possible delay. It must be remembered that when the ordinary processes of manufacture are adopted, the stuff which is collected in the well after the oxidising vat has been drained, will consist, in great part, of a vegetable infusion which is commonly from twenty to twenty-four hours old, and this length of time, at an average temperature of 80° F. or a little over, is abundantly sufficient for the development of a large quantity of organic life and numerous products of decay; but in each succeeding hour the process of putrefaction will progress with increasing rapidity, and one of the main objects of heating the stuff to boiling point is to destroy what organic life there may be, and to arrest putrefaction (or, as planters call it, fermentation). Hence it should be a cardinal maxim with every planter to get through all the earlier steps in indigo manufacture as quickly as circumstances admit of. By the operation of boiling in the boiler it will always be possible to destroy all, or nearly all, the organic life which existed in the stuff passed into the boiler, but the dead bodies of the organisms destroyed will remain mixed with the indigo, and will finally in their dried condition form part of the substance of the finished indigo cakes.

Also, the operation of boiling will arrest decay, but when the contents of the boiler are subsequently spread out upon the tables, living organisms will soon again make their appearance, and the dead bodies of organisms killed in the boiler will afford a good pabulum for the new organisms which will have time to develop on the tables. Hence, if putrid stuff entered the boiler, the boiled stuff when spread on the tables will again become putrid before it can satisfactorily drain and settle, and it will be difficult or impossible to obtain cakes of good quality indigo.

I propose, as an improvement, to do away with the tables altogether; and, instead of spreading out the boiled product upon tables, I would at once transfer it to a filter, where the waste liquor will be drained off by filtration under high pressure.

There are various ways by which filtration under high pressure can be conducted, but the most economical and perhaps the most efficient means is to make use of the pressure of the atmosphere. That pressure is about fifteen pounds to a square inch, and the whole, or nearly the whole, force of the atmospheric pressure may be made use of by placing the filter at the top of a vertical tube a little more than thirty feet long.

My method is as follows :—After the indigo deposit has settled in the oxidising vat, and the waste liquor has been drained off, and the deposited indigo has been collected in a well at the corner of the vat, I proceed at once to strain and filter it, or in cases where a preliminary heating to boiling point may be found advisable or necessary, I strain, boil, and then at once filter. I dispense with the use of settling tables altogether, and, instead, I filter under high pressure. The high pressure I obtain by placing my filtering apparatus at the top of a vertical tube some 30 feet in length. I am thus enabled, by means of the suction effect of a vertical column of liquid of 30 feet in height, to utilise nearly the whole atmospheric pressure of about 15 lbs. to a square inch surface; and besides obtaining a fairly rapid separation of the indigo proper from the waste liquors with which it is mixed, I am enabled to obtain the indigo in a compact form more quickly and more satisfactorily than by any of the means hitherto used. I employ a flat, square, horizontal filtering surface, so that I am able to obtain a square slab of indigo directly from the filter without any intermediate process. I filter through ordinary indigo cloth, supported by sheets of wire gauze resting on a perforated metal plate. The most convenient form to give to the filtering chamber is rectangular, open above, with a square cross section equal to the surface area of the indigo slabs which it may be desired to obtain. The floor of the filtering chamber should converge in all directions towards the exit tube leading from the base of the chamber. That exit tube, which should be about thirty feet in length, should dip at its lower end into a small cavity or tank, with overflow communication with the drainage gutters of the factory, and the tube should be fitted at the bottom with a valve or stopcock, by which it can be opened or closed at will. Also, above the curved or inclined base of the filtering chamber, there should be a horizontal false bottom, fitting accurately against the walls of the chamber.

This false bottom is best constructed of stout rigid perforated metal plate, with numerous perforations, and above this plate there should be several layers of metal gauze of progressive degrees of fineness, the lowest layers coarse and the uppermost fine, and above the uppermost layer of gauze there should be a layer of filtering cloth.

This completes the filtering apparatus, except that there must be an arrangement for taking out the false bottom without disturbing the indigo slab which will rest upon it after filtration is complete. One method for this purpose consists in employing four flat iron bars, terminating above in handles, and connected below with the false bottom, the flat bars sliding close in vertical grooves in the walls of the chamber.

Another method for the same purpose is to adapt the false bottom, made as before described, to the base of a tray, which can be made to slide into and out of the filtering chamber, through a door in one of the sides of the chamber. The tray and the door must both fit true to the walls of the chamber, so as to allow no passage for air or liquid between. To use my apparatus, I first adjust the false bottom in its place. Then having closed the valve or stopcock, at the lowest end of the long tube, I proceed to fill the tube and the lower portion of the filtering chamber up to the upper surface of the false bottom with plain water, and also fill with water the small lower chamber into which the lower end of the tube passes. Then I proceed to fill the upper chamber with the indigo to be filtered, and allow it to settle for a short time, after which I open the stopcock or valve at the bottom end of the tube, and filtration at once commences, and will proceed steadily until at last the indigo will be left in a fairly dry and firm condition, resting on the false bottom. At first and for a very short time a little indigo may be carried through with the filtrate, but the quantity so carried through will be very small, and that small quantity can be preserved by running the first portion of the filtrate into a small reservoir connected by valves with the lower chamber, and so soon as the liquor runs through clear, the lower chamber can be allowed to overflow towards the general drainage system of the factory. If the filtering chamber has sufficient depth it will be found possible to introduce enough indigo at each charging to give a slab of indigo of a suitable thickness for cutting into cakes. If the slab as it is taken from the filtering chamber has not at the time sufficient firmness for cutting, it can then be transferred (while still resting on the false bottom), to a hydraulic or other suitable press of the same cross section, and the consolidation of the slab completed.

The time required for obtaining a slab of indigo fit for cutting into cakes will by this method be diminished by one-half at least as compared with the time required when the ordinary methods are employed, and there will be a considerable saving also of labour and material.

The indigo settling tables in a factory occupy a moderately large surface area. The large cloths for those tables are somewhat expensive, and the lengthened exposure of wet indigo in contact with vegetable infusion to a hot, muggy atmosphere, is prejudicial to the quality of the produce, as before pointed out.

The new method dispenses with settling tables altogether, together with the disadvantageous circumstances which attend their use.

The method which I have described for obtaining an indigo slab by means of high-pressure filters, and without the aid of settling tables, has been patented by me under the Inventions Designs Act of 1888.

This method will be found to work exceptionally well if it is employed on indigo obtained by my method of steeping as described in Chapter I. of this book, and oxidised by my method of falling showers as described in Chapter III.

The indigo obtained by those methods will be exceptionally free from organic contamination, and will therefore allow fluid to travel downwards through the tiny interstices which separate the ultimate indigo particles with greater freedom than when those interstices, or many of them, are blocked by organic slime, as would be the case when the ordinary method of steeping and oxidisation have been employed.

By doing away with the necessity for settling tables, and also by dispensing with all the expensive machinery required for driving paddles for heating the oxidising ranges, the necessity for a large main factory building is done away with, and a comparatively very small factory will suffice where a very large building might otherwise have been required.

Experiments to Illustrate Chapter IV.

(1) Take a long straight water-pipe or gas-pipe tube of about half inch internal diameter, and about 30 ft. in length. Fix this vertically against the wall of your house or factory, so that the bottom of the tube shall dip in a small vessel of water (a deckchi will do).

Next obtain a large, deep funnel of brass or copper, or even of stout tin or iron sheet. The most convenient form to get constructed in the bazaar will be a deep cylinder, terminating in an ordinary funnel below

At the level where the cylinder joins the converging part of the funnel place a circular disc or stout sheet of perforated brass or iron. Over this place a circular disc of fine metal gauze. Then solder the small orifice of the funnel to the top of the vertical tube. Then make a cylindrical bag with circular bottom of indigo cloth, just large enough to fit closely when fully distended to the inside of the cylinder and project a little above its upper edge.

Put this bag in the cylinder and turn over the upper edge, and fasten it tight to the upper rim by fine wire tied round it several times.

Inside the bag place a hollow cylinder of thin sheet tin which shall just fit it, and hold it close to the sides of the outside cylinder.

Then plug the bottom of the long tube with a tight-fitting cork, which must be held in place by strong pressure from below. Now pour water into the vessel in which the bottom of the tube dips until the level of the water in that vessel stands a few inches higher than the bottom orifice of the tube.

Next pour water in at the top of the cylinder, and go on pouring until the water level has risen to the top edge of the cylinder.

Then unplug the bottom of the tube, and let water flow out until the water level in the cylinder has fallen nearly to the level of the bottom of the bag.

Then plug the bottom of the tube again, and afterwards fill up the cylinder with freshly collected indigo deposit just as it can be ladled up from the well of an oxidising tank. Pass this through a strainer into the bag till the bag is full. Then let it rest for half an hour, after which open the plug at the base of the tube, and this time leave it open. *Watch what comes down the tube.* Observe that for some little time the liquor will contain some indigo. Collect the liquor so long as it contains suspended indigo, and then let it stand awhile; afterwards collect, dry, and weigh the deposit, and observe what proportion it bears to the indigo retained in the filter. Observe the time which elapses before the whole visible supply of liquor put into the cylinder has passed through the indigo in the filter. Observe how the deposit on the filter gradually consolidates.

Finally, remove the innermost hollow tin cylinder; then the upper edges of the bag, and remove that bag with its contents, and study the indigo thus obtained.

(2) Repeat the last experiment several times with variations, specially as regards time and the quantity of the indigo stuff poured into the filter.

(3) Try, side by side, two filters of precisely similar construction, except that one will have the ordinary short funnel neck termination, and the other the long vertical tube of 30 feet. Note the difference of time required for filtration in the two cases, and the great difference in the compactness of the indigo slabs obtained.