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III. *On the Production of Cast Iron, and the Operations of the Blast-Furnace.* By Mr. DAVID MUSHET, of the Clyde Iron-Works. Communicated by the Author.

IT was my wish, in the papers preceding this communication, to convey a clear and competent idea of the nature of iron as a metal; as also of ores, and iron-stones in general. I have endeavoured to explain, upon principles grounded on experiment, the chief agents of change in the smelting operation, so far as they affect the quality of the materials prepared. I have aimed at perspicuity rather than minuteness, which often becomes tedious; and although the facts may not be conveyed in a style so popular as communications, which profess a conveyance of practical truths, generally are, yet, I trust, this will form no real bar to their utility. When facts are to be learned, and principles satisfactorily explained, it is surely best to begin by the examination of simple causes; and tracing their agency according to their quantities, relative proportions, and affinities. These facts will undoubtedly, in the end, be more radically understood by using such phrases, or signs, as denote in each a respective quality affixed in consequence of a knowledge of its properties and effects. In short, if the language and reasoning of our manufactures is ever to become scientific; if philosophy and chemistry are ever to become of general utility in the perfection of any branch; then those truths which constitute the foundation of all science are not to be rejected, though clothed in a dress which at first sight appears discordant to our habits, or burdensome to our memory.

The operations I am about to describe have never as yet received any explanation consonant to true philosophy or chemical facts; yet there are few which present a more beautiful chain of affinities, decomposition, and recombination, than the manufacture of iron in all its various stages. An extensive foundry is a laboratory fraught with phenomena of the most interesting nature in chemistry and natural philosophy: are we not then justly surprised to find that prejudice still

still reigns there; and that the curious manipulations of these regions are still shrouded with error and misconception; as if their dingy structure forbade the entrance of genius, or consigned her laborious unlettered sons to an endless stretch of mental obscurity?

The plate of the blast-furnace, given in the preceding Number, having a full description appropriated to it, I shall proceed to detail the train of preparation necessary before the furnace is brought to produce good melting iron.

The furnace being finished, the bottom and sides of it, for two feet up the square funnel, receive a lining of common bricks upon edge, to prevent the stone from shivering or mouldering when the fire comes in contact with it. On the front of the furnace is erected a temporary fire-place, about four feet long, into the bottom of which are laid corresponding bars. The side-walls are made so high as to reach the under-surface of the tympan-stone; excepting a small space, which afterwards receives an iron plate of $1\frac{1}{2}$ inches thickness, by way of a cover: this also preserves the tympan-stone from any injury it might sustain by being in contact with the flame. A fire is now kindled upon the bars and is fed occasionally with small coals. As the whole cavity of the furnace serves as a chimney for this fire, the draught in consequence is violent, and the body of heat carried up is very considerable. In the course of three weeks the furnace will thus become entirely free from damp, and fit for the reception of the materials: when this is judged proper the fire-place is removed, but the interior bricks are allowed to remain till the operation of blowing commences. Some loose fuel is then thrown upon the bottom of the furnace, and a few baskets of coals are introduced; these are allowed to become thoroughly ignited before more are added. In this manner the furnace is gradually filled; sometimes entirely full, and at other times 5-8ths or 3-4ths full. The number of baskets full depend entirely upon the size of the furnace: that in the plate will contain 900 baskets. If the coal is splint, the weight of each basket-full will be nearly $110\text{ lb.} \times 900 = 99,000\text{ lb.}$ coals. As this quality of coals is made with a loss of nearly 50 *per cent.* the original weight in raw coals

coals will be equal to 198,000 lb. When we reflect that this vast body of ignited matter is replaced every third day, when the furnace is properly at work, a notion may be formed of the immense quantity of materials requisite, as also the consequent industry exerted to supply one or more furnaces for the space of one year.

When the furnace is sufficiently heated throughout, specific quantities of cokes, iron-stone, and blast-furnace cinders are added: these are called charges. The cokes are commonly filled in baskets, which, at all the various iron-works, are nearly of a size. The weight of a basket, however, depends entirely upon the nature and quality of the coal, being from 70 to 112 lb. each *. The iron-stone is filled into boxes, which, when moderately heaped, contain 56 lb. of torrefied iron-stone; they often exceed this when the stone has been severely roasted. The first charges which a furnace receives, contain but a small proportion of iron-stone to the weight of cokes: this is afterwards increased to a full burden, which is commonly 4 baskets cokes, 320 lb.; 2 boxes iron-stone, 112 lb.; 1 box blast-furnace cinders, 60 or 70 lb.† At new works, where these cinders cannot be obtained, a similar quantity of limestone is used.

The descent of the charge, or burden, is facilitated by opening the furnace below two or three times a-day, throwing out the cold cinders, and admitting, for an hour at a time, a body of fresh air. This operation is repeated till the approach of the iron-stone and cinder, which is always announced by a partial fusion, and the dropping of lava through the iron bars, introduced to support the incumbent materials while those on the bottom are carried away. The filling above is regularly continued, and when the furnace at the

* This same variety in the coal renders it almost impossible, under one description, to give a just idea of the proportions used at various blast-furnaces: to avoid being too diffuse, I shall confine my description connected with a coal of a medium quality, or a mixture of splint and free-coal, a basket of which will weigh from 78 lb. to 84 lb.

† A preference at first is always given to blast-furnace cinders in place of lime; being already vitrified, they are of much easier fusion, and tend to preserve the surface of the hearth by glazing it over with a black vitrid crust.

top has acquired a considerable degree of heat, it is then judged time to introduce the blast; the preparations necessary for which are the following:—

The dam-stone is laid in its place firmly imbedded in fire-clay; the dam-plate is again imbedded on this with the same cement, and is subject to the same inclination. On the top of this plate is a slight depression, of a curved form, towards that side farthest distant from the blast, for the purpose of concentrating the scoria, and allowing it to flow off in a connected stream, as it tends to surmount the level of the dam. From this notch to the level of the floor a declivity of brick-work is erected, down which the scoria of the furnace flows in large quantities. The opening betwixt the dam and side-walls of the furnace, called the *fauld*, is then built up with sand, the loose bricks are removed, and the furnace bottom is covered with powdered lime or charcoal-dust. The ignited coles are now allowed to fall down, and are brought forward with iron bars nearly to a level with the dam. The space between the surface of the coles and the bottom of the tymplate is next rammed hard with strong binding sand; and these coles, which are exposed on the outside, are covered with coke-dust. These precautions being taken, the tuyere-hole is then opened and lined with a soft mixture of fire-clay and loam: the blast is commonly introduced into the furnace at first with a small discharging-pipe, which is afterwards increased as occasion may require. In two hours after blowing, a considerable quantity of lava will be accumulated; iron bars are then introduced, and perforations made in the compressed matter at the bottom of the furnace; the lava is admitted to all parts of the hearth, and soon thoroughly heats and glazes the surfaces of the fire-stone. Shortly after this it rises to a level with the notch in the dam-plate, and by its own accumulation, together with the forcible action of the blast, it flows over. Its colour is at first black; its fracture dense, and very ponderous; the form it assumes in running off is flat and branched, sometimes in long streams, and at other times less extensive. If the preparation has been well conducted, the colour of the cinder will soon change to white; and the metal, which in the state of an oxyde formerly

coloured

coloured it, will be left in a disengaged state in the furnace. When the metal has risen nearly to a level with the dam, it is then let out by cutting away the hardened loam of the fault, and conveyed by a channel, made in sand, to its proper destination; the principal channel, or runner, is called the *fow*, the lateral moulds are called the *pigs*.

In six days after the commencement of blowing, the furnace ought to have *wrought herself clear*, and have acquired capacity sufficient to contain from 5000 to 7000 weight of iron. The quality ought also to be richly carbonated, so as to be of value and estimation in the pig-market. At this period, with a quality of coal as formerly mentioned, the charge will have increased to the following proportions:—5 baskets coles, 400lb.; 6 boxes iron-stone, 336lb.; 1 box limestone, 100lb.

An analysis of the smelting operation, and the tendency which the individual agents have to produce change in the quality and quantity of the iron, come next under consideration. Let us, however, first notice the characteristic features exhibited by the different kinds of iron while in fusion, whereby the quality of the metal may be justly defined.

When fine (No. 1.) or supercarbonated crude iron is run from the furnace, the stream of metal, as it issues from the fault, throws off an infinite number of brilliant sparkles of carbon. The surface is covered with a fluid pellicle of carburet of iron, which, as it flows, rears itself up in the most delicate folds: at first the fluid metal appears like a dense, ponderous stream, but, as the collateral moulds become filled, it exhibits a general rapid motion from the surface of the pigs to the centre of many points; millions of the finest undulations move upon each mould, displaying the greatest nicety and rapidity of movement, conjoined with an uncommonly beautiful variegation of colour, which language is inadequate justly to describe. Such metal, in quantity, will remain fluid for twenty minutes after it is run from the furnace, and when cold will have its surface covered with the beautiful carburet of iron, already mentioned, of an uncommonly rich and brilliant appearance. When the surface of the metal is not carbureted, it is smooth like forged iron, and
always

always convex. In this state iron is too rich for melting without the addition of coarse metal, and is unfit to be used in a cupola furnace for making fine castings, where thinness and a good skin are requisite.

No. 4, or oxygenated crude iron, when issuing from the blast-furnace, throws off from all parts of the fluid surface a vast number of metallic sparks: they arise from a different cause than that exerted in the former instance. The extreme privation of carbon renders the metal subject to the combination of oxygen so soon as it comes into contact with atmospheric air. This truth is evidently manifested by the ejection of small spherules of iron from all parts of the surface: the deflagration does not, however, take place till the globule has been thrown two or three feet up in the air; it then inflames and separates, with a slight hissing explosion, into a great many minute particles of brilliant fire. When these are collected they prove to be a true oxide of iron, but so much saturated with oxygen as to possess no magnetic obedience. The surface of oxygenated iron, when running, is covered with waving flakes of an obscure smoky flame, accompanied with a hissing noise; forming a wonderful contrast with the fine rich covering of plumbago in the other state of the metal, occasionally parting and exhibiting the iron in a state of the greatest apparent purity, agitated in numberless minute fibres, from the abundance of the carbon united with the metal.

When iron thus highly oxygenated comes to rest, small specks of oxide begin to appear floating upon the surface: these increase in size; and when the metal has become solid, the upper surface is found entirely covered with a scale of blue oxide of various thicknesses, dependent upon the stage of oxygenation or extreme privation of carbon. This oxide, in common, contains about 15 *per cent.* of oxygen, and is very obedient to the magnet. In place of a dark blue smooth surface, convex and richly carbonated, the metal will exhibit a deep, rough, concave face, which, when the oxide is removed, presents a great number of deep pits. This iron in fusion stands less convex than carbonated iron, merely because it is less susceptible of a state of extreme division; and

indeed it seems a principle in all metallic fluids, that they are convex in proportion to the quantity of carbon with which they are saturated. This iron flows dead and ponderous, and rarely parts in shades but at the distance of some inches from each other.

This is a slight sketch of the appearance of the two extreme qualities of crude, or pig-iron, when in a state of fusion. According to the division formerly made, there still remains two intermediate stages of quality to be described: these are, carbonated and carbo-oxygenated iron; that is, No. 2 and 3 of the manufacturers. Carbonated iron exhibits, like No. 1, a beautiful appearance in the runner and pig. The breakings of the fluid, in general, are less fine; the agitation less delicate; though the division of the fluid is equal, if not beyond that of the other. When the internal ebullition of the metal is greatest, the undulating shades are smallest and most numerous: sometimes they assume the shape of small segments; sometimes fibrated groups; and at other times minute circles, of a mellow colour than the ground of the fluid. The surface of this metal, exposed to external air, when cooling is generally slightly convex, and full of punctures: these, in iron of a weak and fusible nature, are commonly small in the diameter, and of no great depth. In strong metal, the punctures are much wider and deeper. This criterion, however, is not infallible, when pig-iron of different works is taken collectively. At each individual work, however, that iron will be strongest whose honey-combs are largest and deepest.

Carbo-oxygenated, or No. 3, pig-iron, runs smoothly, without any great degree of ebullition or disengagement of metallic sparks. The partings upon its surface are longer, and at greater distances from each other than in the former varieties; the shape they assume is either elliptical, circular, or curved. In cooling, this metal acquires a considerable portion of oxyde; the surface is neither markedly convex nor concave; the punctures are less, and frequently vanish altogether. Their absence, however, is no token of a smooth face succeeding: in qualities of crude iron oxygenated beyond this, I have already mentioned that a concave surface

Is the consequence of the extreme absence of carbon; and that, in proportion as this principle is absent, the surface of the iron acquires roughness and asperity.

It may perhaps be proper here to mention, once for all, that although, for convenience, the manufacturer has, from a just estimation of the value of the metal in a subsequent manufacture, affixed certain numbers for determinate qualities of iron, yet it is difficult to say at what degree of saturation of carbon each respective term commences: suffice it then to say, that the two alternative principles, oxygen and carbon, form two distinct classes, that in which oxygen predominates, and that in which carbon predominates; the latter comprehends No. 1 and 2 of the manufacturers, the former includes oxygenated, white and mottled; and the equalisation of these mixtures form, as has already been noticed, the variety of carbo-oxygenated crude iron.

I shall now observe some things relative to the various faces which crude iron assumes. No. 1 and 2, with their intermediate qualities, possess surfaces more or less convex, and frequently with thin blisters: this we attribute to the presence of carbon, which being plentifully interspersed betwixt and throughout the particles of the metal, the tendency which the iron has to shrink in cooling is entirely done away; it tends to distend the aggregate of the mass, and to give a round face, by gradually elevating the central parts of the surface, which are always left to lose their fluidity.

Again, that quality of iron known by the name of No. 3, or carbo-oxygenated, is most commonly found with a flat surface. If we still farther trace the appearance of the surface of pig-iron, when run from the furnace, we shall find No. 4, either with a white or mottled fracture, possessed of concave faces rough and deeply pitted. Beyond this it may be imagined that every degree of further oxygenation would be productive of a surface deeper in the curve, and rougher, with additional asperities. The contrary is the case: when crude iron is so far debased as to be run from the furnace in clotted lumps highly oxygenated, the surface of the pigs is found to be more convex than that of No. 1 iron; but then

the fracture of such metal presents an impure mass covered on both faces with a mixture of oxydated iron, of a blueish colour, nearly metallic. In short, this quality of iron is incapable of receiving such a degree of fluidity as to enable us to judge whether the convexity of its surface is peculiar to its state, or is owing to its want of division as a fluid, whereby the gradual consolidation of the metal is prevented.

These features sufficiently distinguish betwixt the various qualities of crude iron after they are obtained from the blast-furnace: there are, however, criterions not less infallible, whereby we can prejudge the quality of the metal many hours before it is run from the furnace. These are the colour and form of the scoria, the colour of the vitrid crust upon the working bars, and the quantity of carburet which is attached to it. The variety of colour and form in the cinder almost universally indicate the quality of the metal on the hearth. Hence, from a long course of experience, have arisen the following denominations: "Cinder of sulphury iron;" "Cinder of No. 1, No. 2, and No. 3;" and "Cinder of ballast iron." Although at different works, from local circumstances, the same kind of scoria may not indicate precisely the same quality of iron, yet the difference is so small that the following description of the various cinders may convey a very just idea of their general appearance.

When the scoria is of a whitish colour and short form, branching from the notch of the dam, and emitting from its stream beautiful sparks of ignited carbon, resembling those ejected from a crucible of cast steel in fusion, exposed to external air, or to the combustion of fine steel filings in a white flame; if, when issuing from the orifice of the furnace, it is of the purest white colour, possessing no tenacity, but in a state of the greatest fluid division, and, when cold, resembles a mass of heavy torrefied spar, void of the smallest vitrid appearance, hard and durable, it is then certain that the furnace contains *fulbury iron*, i. e. super-carbonated iron. At blast-furnaces, where a great quantity of air is thrown in *per minute*, super-carbonated crude iron will be obtained with a cinder of a longer form, with a rough flinty fracture towards the outside of the column.

That

That cinder which indicates the presence of carbonated iron in the hearth of the furnace, forms itself into circular compact streams, which become consolidated and inserted into each other; these are in length from three to nine feet. Their colour, when the iron approaches the first quality, is a beautiful variegation of white and blue enamel, forming a wild profusion of the elements of every known figure; the blues are lighter or darker according to the quantity of the metal and the action of the external air while cooling. When the quality of the pig-iron is sparingly carbonated, the blue colour is less vivid, less delicate; and the external surface rougher, and more sullied with a mixture of colour. The same scoria, when fused in vessels which are allowed to cool gradually, parts with all its variety of light and shade, and becomes of a yellowish colour, sometimes nearly white when the quantity of incorporated metal has been small.

The cinder which is emitted from the blast-furnace when carbo-oxygenated (or No. 3,) iron is produced, assumes a long zig-zag form. The stream is slightly convex in the middle; broad, flat, and obliquely furrowed towards the edges. The end of the stream frequently rears itself into narrow tapered cones, to the height of six or eight inches: these are generally hollow in the centre, and are easily demolished, owing to their excessive brittleness. The colour of this lava is very various; for the most part it is pale yellow mixed with green. Its tenacity is so great, that if, while fluid, a small iron hook is inserted into it at a certain degree of heat, and then drawn from it with a quick but steady motion, 20 to 30 yards of fine glass thread may be formed with ease. If the colours are vivid and variegated, the thread will possess, upon a minute scale, all the various tints of colouring which is found in the columnar mass. When by accident a quantity of this lava runs back upon the discharging-pipe, it is upon the return of the blast impelled with such velocity as to be blown into minute delicate fibres, smaller than the most ductile wire; at first they float upon the air like wool, and when at rest very much resemble that substance.

The presence of oxygenated crude iron (No. 4,) on the furnace-

furnace-hearth, is indicated by the lava resolving itself into long streams, sometimes branched, sometimes columnar, extending from the notch to the lowest part of the declivity; here it commonly forms large, flat, hollow cakes, or inclines to form conical figures: these are, however, seldom perfect; for the quantity of fluid lava, conveyed through the centre of the column, accumulates faster than the external sides of the cone are consolidated; and thus, when the structure is only half finished, the small crater vomits forth its superabundant lava, and is demolished. The current of such lava falls heavily from the dam as if surcharged with metal, and emits dark red sparks resembling the agitation of straw embers. Its colour is still more varied than the former descriptions of scoriæ, and is found changing its hues through a great variety of greens shaded with browns. Another variety of scoria, which indicates the same quality of iron, assumes a similar form; but has a black ground colour mixed with browns, or is entirely black. When the latter colour prevails, the texture of the cinder becomes porous; the quantity of iron left is now very considerable, and such as will be easily extracted in the assay-furnace with proper fluxes. In cases of total derangement in the furnace, the scoria will still retain this black colour, although the quantity of metal may amount to 25 *per cent.*; the fracture, however, becomes dense, and its specific gravity increases in proportion to the quantity of metal it holds incorporated.

The next source of information, as to the quality of the iron in the furnace, is to be got from the colour of the scoria upon the working bars, which are from time to time inserted to keep the furnace free from lumps, and to bring forward the scoria. When super-carbonated crude iron is in the hearth, the vitrid crust upon the bars will be of a black colour and smooth surface, fully covered with large and brilliant plates of plumbago.

As the quality of the metal approaches to No. 2 (carbonated), the carburet upon the scoria decreases both in point of quantity and size.

When carbo-oxygenated iron (No. 3) is in the furnace, the working bars are always coated with a lighter coloured

loured scoria than when the former varieties exist; a speck of plumbago is now only found here and there, and that of the smallest size. When the quality of the metal is oxygenated (No. 4.), not only have the plates of carburet disappeared, but also the coally colour on the external surface of the scoria; what now attaches to the bars, is nearly of the same nature and colour as the lava emitted at the notch of the dam.

These criterions are infallible; for, as the fusibility or carbonation of the metal is promoted in a direct ratio to the comparative quantity of the coally principle present in the furnace, so in the same proportion will the vitrid crust encircling the working bars exhibit the presence of that principle in the furnace.

IV. *Agenda, or a Collection of Observations and Researches, the Results of which may serve as the Foundation for a Theory of the Earth.* By M. DE SAUSSURE.

[Continued from Page 29.]

CHAP. XXII.

Errors to be avoided in Observations respecting Geology.

1. **T**HERE are some errors into which people may readily fall when they have not had long experience in any given kind of observation, and against which it is of importance to put beginners at least on their guard.

2. One may be readily deceived in regard to the relative distances of remote objects. All the stars and planets appear to be at an equal distance from us. Distant mountains all appear to be in the same plain. Thus those which are situated very far behind the rest, seem to form one body with them; so that people believe they see continued and uninterrupted chains when there are really none, and where the mountains, on the contrary, are insulated.

The absolute distance of objects, even when not very remote, is equally difficult to be ascertained on high mountains,