

oxygen gases between the pressures mentioned has been investigated. The results confirm the applicability of Boyle's law. In the case of oxygen nothing has been seen of the anomalies encountered by Bohr, especially in the neighbourhood of a pressure of 0.7 mm.

"An Investigation of the Spectra of Flames resulting from Operations in the Open-hearth and 'Basic' Bessemer Processes." By W. N. HARTLEY, F.R.S., Royal College of Science, Dublin, and HUGH RAMAGE, A.R.C.Sc.I., St. John's College, Cambridge. Received November 15, 1900,—Read February 21, 1901.

(Abstract.)

Three papers on "Flame Spectra," by one of the authors, were published in the 'Philosophical Transactions' for 1894. Parts I and II, "Flame Spectra at High Temperatures," and Part III, "The Spectroscopic Phenomena and Thermochemistry of the Bessemer Process." The results in the last of these papers had reference to the phenomena observed in the flames of the "acid" Bessemer process; the present paper deals mainly with an investigation of the Thomas-Gilchrist or "basic" process.

The Cleveland district of Yorkshire was chosen as the principal centre; owing to the interest taken in the work by Mr. Arthur Cooper, Past President of the Iron and Steel Institute, and in consequence of the courtesy and attention shown us, the North Eastern Steel Company's works at Middlesbrough were selected.

It was found necessary at the outset to have three observers at work simultaneously, and the authors were voluntarily and ably assisted by Mr. E. V. Clark, A.R.S.M. Photographs of the plant and the flames, at different periods of the blow, were secured by means of a small Anschütz camera and Goertz lens; eye observations were made with a small direct-vision spectroscope; photographs of spectra were taken with the spectrograph described in 'Philosophical Transactions,' A, vol. 185, p. 1047, and the times of the exposures, &c., were observed and recorded in a note-book. This work was not accomplished without some difficulty, which was occasioned by the large quantity of lime dust blown into the air.

The spectroscopic results were quite different from those previously obtained, as the continuous spectrum was much stronger. Many lines and bands new to the Bessemer flame spectra have been observed in addition to the spectra of the common alkali metals, iron, and manganese. Thus rubidium, caesium, calcium, copper, silver, and gallium have been identified. The crude iron, the ores, limestone,

lime, slags, flue dust, and the finished steel have all been analysed, and their constituent elements have been traced all through the process of manufacture.

While no indication was obtained of the amount of phosphorus in the metal during the process of "blowing," some insight into the chemistry of the process has been obtained. The greatest interest, however, is attached to the knowledge it has given us of flame spectra under variations of temperature, and of the wide distribution of many of the rarer elements in minute proportions in ores and common minerals.*

Comparison of Spectra from Open-hearth and Cupola Furnaces.

Early in 1895, by kind permission of Mr. F. W. Webb, the flame over the hearth of a Siemens' open hearth steel furnace in Crewe works was examined spectroscopically, but no lines of metals except sodium were detected. The continuous spectrum of the light emitted by the walls was very strong, and extended to wave-length 3470. Observations were also made at this time on the spectra of the flame above the charge in a cupola. While the blast was turned on the flame was bluish, and lines of sodium, lithium, and potassium were observed. When the blast was stopped, the flame became smaller and whiter, and the lines of the above elements became stronger; the ends of the two strongest bands of manganese were also seen.

Description of the "Blow" and "Over Blow" in the Basic Bessemer Process.

The converter is first charged with about two tons of lime in lumps, and then with twelve tons of fluid "mixer metal," a mixture of metal coming direct from the blast furnace, and molten pig iron from the cupolas. The blast is turned on and the vessel rotated into a nearly vertical position.

The "blow" may be divided into three stages. The first stage ends when the flame drops, indicating that the carbon has been burnt. The second stage ends when the vessel is turned down for a sample of metal to be taken out and the slag poured off. More lime is then added and the blow is continued for a few seconds longer to complete the removal of the phosphorus; this forms the third stage. The average duration of the first stage was twelve minutes and twenty seconds, and of the second stage, five and a half minutes.

The blow began with the expulsion of a large quantity of lime dust, which hid everything from view for a minute or two and covered

* 'Roy. Soc. Proc.' vol. 60, pp. 35 and 393; 'Chem. Soc. Trans.' 1897, pp. 533 and 547.

the instruments and observers. A flame was visible at the mouth of the converter as soon as the cloud of dust had cleared away; this had a yellow or yellowish-red colour. The flame grew rapidly in length and remained clear as in the "acid" process, until it dropped and the second stage began. In this stage the flame was very short, and a large quantity of fume was expelled from the vessel; the flame grew longer and the quantity of fume increased as the "blow" proceeded.

Twenty-six plates of spectra were photographed; some of these were very sharp and gave a complete record of substances present in the flame at intervals of one minute throughout the blow. Careful measurements of the best spectra have been made, and the wavelengths of the lines and bands recorded. The others, not measured in detail, have been compared with these, but no lines or bands occur in them which do not also occur in the best plates. A plate of spectra was usually taken by giving the same time of exposure to each spectrum of the series until the flame dropped; two further exposures were then made on the flame of the over-blow. The spectra increase in intensity as the blow proceeds in the first stage, and this can only result from a corresponding increase in the temperature of the bath of metal and of the flame.

Much detail was lost in many of the spectra, by the interference of the light reflected from a large quantity of white dust and smoke in the air in the neighbourhood of the converters. The converter nearest the observers was the only one of the four from which delicate detail was obtainable, and this was only secured by working in the evening when the sun was very low, or after it had set.

Considerable difficulty was experienced in the identification of some of the lines and bands. This was due partly to the comparatively small dispersion in the less refrangible portion of the green and red rays, by which lines and the sharp edges of bands were almost indistinguishable on the strong continuous spectrum. In other cases, lines were present which had not been observed in flame spectra before, some due to uncommon elements, and others were relatively much stronger than a study of the oxyhydrogen flame and other spectra of the same metals led us to expect.

Conclusions.

(1.) *Line spectra are not observed in the open-hearth furnace.* This is attributed mainly to the fact that the atmosphere of the furnace is oxidising, and under these conditions, as Gouy has shown,* only sodium gives a spectrum approaching in intensity that which it gives in a reducing flame. The D lines were observed by eye observation, but did not appear on the photographs.

* 'Phil. Mag.,' vol. 2, 1877, p. 156.

(2.) *The phenomena of the "basic" Bessemer blow differ considerably from those of the "acid" process.*

First, a flame is visible from the commencement of blowing, or as soon as the cloud of lime dust has dispersed. We conclude that the immediate production of this flame is caused by carbonaceous matter in the lining of the vessel, that its luminosity is due partly to the volatilisation of the alkalies, and to the incandescence of lime dust carried out by the blast.

Secondly, volatilisation of metal occurs largely at an early period in the blow, and is due to the difference in composition of the metal blown, chiefly to the smaller quantity of silicon. There is practically no distinct period when silicious slags are formed in the "basic" process, and metals are volatilised readily in the reducing atmosphere, rich in carbon monoxide.

Thirdly, a very large amount of fume is formed towards the close of the second period. This arises from the oxidation of metal and of phosphorus in the iron phosphide being productive of a high temperature, but little or no carbon remaining. The flame is comparatively short, and the metallic vapours carried up are burnt by the blast.

Fourthly, the "over-blow" is characterised by a very powerful illumination from what appears to be a brilliant yellow flame: a dense fume is produced at this time composed of oxidised metallic vapours, chiefly iron. These particles are undoubtedly of very minute dimensions, as is proved by the fact that they scatter the light which falls on them, and the cloud casts a brown shadow, and, on a still day, ascends to a great height. The spectrum is continuous, but does not extend beyond wave-length 4000. This indicates that the source of light is at a comparatively low temperature, approaching that of a yellowish-white heat. We conclude, therefore, that the light emanates from a torrent of very small particles, liquid or solid, at a yellowish-white heat. The "flame" can have but little reducing power at this stage, and this, together with its low temperature, accounts for the very feeble lines of lithium, sodium, potassium, and manganese seen in the photographs, or by eye observations.

Fifthly, the spectra of flames from the first stage of the "basic" process differ from those of the "acid" process in several particulars. The manganese bands are relatively feeble, and lines of elements, not usually associated with Bessemer metal, are present. Both the charges of metal and of "basic" material contribute to these. Lithium, sodium, potassium, rubidium, and caesium have been traced mainly to the lime; manganese, copper, silver and gallium to the metal. Other metals, such as vanadium and titanium, are not in evidence, because they do not yield flame spectra; they, together with chromium, pass into the slag in an oxidised state.

(3.) *Differences in the intensity of metallic lines.* The intensity of

the lines of any metal varies with the amount of the metal in the charge, but in some cases variations of intensity occur among the lines of one metal as observed in the spectra photographed at Crewe in 1893; especially is this the case with some lines in the visible spectrum of iron.

These variations are due to changes in temperature; as the temperature of the flame rises, some lines fade almost away, others become stronger. The changes are more marked in the arc spectrum and still more in the spark spectrum of iron.

Lines of potassium and the edges of manganese bands are shown to have been intensified by the proximity of iron lines in some cases, but this is doubtless a result of low dispersion. The two violet rubidium lines nearly coincide with two lines of iron.*

A new line of potassium with variable intensity. This line, wavelength approximately 4642, varies in intensity within somewhat wide limits. In a given flame its brilliancy is increased by diminishing the quantity of metallic vapour in the flame: this does not appear to depend altogether on the weakening of the continuous spectrum; it is probably due, in part at least, to the increased freedom of motion permitted to the molecules of the metal.

“The Mineral Constituents of Dust and Soot from various Sources.” By W. N. HARTLEY, F.R.S., Royal College of Science, Dublin, and HUGH RAMAGE, A.R.C.So.I., St. John’s College, Cambridge. Received November 20, 1900—Read February 21, 1901.

Baron Nordenskjöld has described three different kinds of dust which were collected by him.† Of two of these, one consisted of diatomaceæ and another of a silicious and apparently felspathic sand: both were found on ice in the Arctic regions. The third variety was quite different and appeared to be of cosmic origin. He observed that some sand collected at the end of a five or six days’ continuous fall was mingled with a large quantity of sooty-looking particles, consisting of a material rich in carbon. It appeared to be similar to the dust which fell, with a shower of meteorites, at Hessel near Upsala in the beginning of the year 1869. As in this particular instance it might be supposed that the railways and houses of Stockholm had contributed some of this matter to the atmosphere, and that the snow had carried it down, he requested his brother, who then resided in a desert district of Finland, to give his attention to the subject, with

* ‘Roy. Dublin Soc. Proc.’ vol. 8 (N.S.), Part VI, p. 705.

† ‘Comptes Rendus,’ vol. 78, p. 236.