

TABLE II.

System.	Horsfall.		Dörr.	Herbertz.	Humboldt.	Heenan.	Hamburg.
City.	Hamburg (old).	Zürich.	Wiesbaden.	Frankfurt.	Fürth.	Milwaukee.	Hamburg (new).
Size of plant	36 cells	12 cells	6 furnaces	6 × 4 cells	2 furnaces	3 × 4 cells	12 furnaces
Total daily capacity in tons	180	120	108	180	53	225	500
Total	£ 24,000	28,250	17,750	69,000	5000 + 2500	45,000	57,000
Initial cost					(for additions) 142.5		
Total per ton of daily capacity	£ 133.5	235	164	382.5	1011 eventually	200	115
Actual daily capacity in tons ..	170	68	55	150	16	174	325
Actual annual capacity in tons	53,000	20,000	17,000	46,500	5000	54,000	100,000
Cost of operation	£ 5050	5875	2400	7700	7830	13,250	980
Do. per ton of actual capacity	shillings 2.25	3.85	2.80	3.30	3.15	2.75	1.96
Cost of operation, including 10 per cent. interest and sinking fund	£ 8350	6700	4175	14,600	1533	2400	17,750
Per ton of refuse	shillings 3.15	6.70	4.90	6.30	6.15	4.00	3.10

TABLE III.

System.	City.	Grate area sq. metres.	Max. capacity per cell per day. Kilos.	Capacity per hour per sq. m. of grate.
Horsfall	Hamburg	2.75	5000	{ 76 133 220
	Zürich	1.80	6750	133
	Brüssels	2.5	10,000	133
Heenan	Milwaukee	2.5	4 cells 60,000	335
	Dublin	2.7	2 × 3 100,000	260
	Cheltenham	2.7	4 60,000	235
	Vancouver	3.0	3 55,000	255
	Coventry	2.7	3 75,000	385
Herbertz	Flume	1.25		345.75
	Brünn	1.25	7 60,760	325
	Kiel	0.94	6 60,000	445
	Frankfurt	1.1	4 30,000	285
		2.2	2 50,000	480
Humboldt	Fürth	1.5	27,500	720
Dörr	Wiesbaden	1.0	19,500	815
Hamburg	Hamburg	1.2	44,000	1530

in which the refuse is collected and dump the contents on a large platform whence the refuse is conveyed in wheelbarrows to a feeding stage adjoining the platform. At first the circular trough between the exterior bell and the hopper-shaped opening of the furnace is filled. By lifting the bell the refuse drops into the funnel and the outer bell is closed. The inner bell is then raised and the refuse falls on to the grate so that the furnace is never actually open. The charging by hand was retained here on account of the existing haulage method, and a further reason was that Hamburg would not abandon this system as shells and other explosive matter have frequently been found in the waste and accidents have occurred. A third reason was the extremely varying composition of the Hamburg garbage, in which big pieces exist up to 1 yard long, which would require large buckets. Experiments with such a construction had but unfavourable results.

However, there is no reason to continue the charging by the double bell method, which is used exclusively in the blast-furnace with bucket feeding, or to empty the wagon-bodies directly into the mouth of the bell as it is done with the Ochsen system (see Fig. 7).

The Hamburg plant is at present not in a position to sell steam or electric power like other incinerator plants. Still a considerable revenue appears in the annual reports from the sale of the slag, which has proved to be valuable as a substitute for gravel in mixing concrete or as a filling material for road construction and covering old dumping grounds.

A concise idea of the costs and efficiency of the various types can be obtained from Tables II. and III.

From the above it will be seen clearly that an incinerator should be of the simplest and most efficient type, and of the lowest cost, which is without doubt that of the shaft furnace.

Liverpool Section.

Meeting held at the University on Wednesday, January 28th, 1914.

PROF. E. C. C. BALY IN THE CHAIR.

COAL AND THE CHEMISTRY OF ITS CARBONISATION.

BY JOHN HARGER, M.Sc., Ph.D. M.Inst.M.E.

Very little is known of the chemical composition of the various constituents of coals though some progress has been made by various workers in separating them by the solvent action of pyridine, as discovered by Professor P. Bedson. Some coals, such as anthracite, semi-anthracite, and steam coals, yield very little pyridine-soluble matter, neither do brown coals nor cannel coals yield very much, but some bituminous coals give as much as 40 per cent. extract. The utility of the pyridine extraction method is however impaired by the facts that the ultimate chemical

analyses of the soluble and insoluble portions from the same bituminous coal differ very little, and that, up to now, all the fractions contain more nitrogen than the original coal, indicating that some pyridine, in spite of all the precautions employed to remove it, has been retained by the coal substances. By the usual Soxhlet method the quantity slowly dissolved by pyridine is large at first, then more is dissolved very slowly indeed. An extraction usually extends over two weeks at least.

The author has lately found that a better method is to take a small quantity of the finely powdered coal (passing through 120 mesh sieve), say about one gram, add 150 grams of pyridine, seal in a strong glass tube and heat to about 160–180° C. for twenty-four hours. By this method more extract is obtained in twenty-four hours than by the usual method in months.

The chemists at the Government Experimental Station at Eskmeals have found that the inflammability of coal-dust is in proportion to the quantity soluble in pyridine. The French Government chemists, however, have found that, for French coals at least, this relation does not apply. The author has found that cannel coal contains very much less soluble in pyridine than ordinary bituminous coals, e.g., by the Soxhlet method. Old Roundwood cannel yields 15½ per cent. and Lancashire Arley coal 22½ per cent., yet there is no doubt whatever that the cannel dust is far more inflammable than the dust of the Arley coal, each of the same degree of fineness. It was found, however, that Arley coal dust, which gave only 22½ per cent. soluble in pyridine by two weeks' extraction in the Soxhlet, gave 40½ per cent. soluble in pyridine by the sealed tube method. 150 grams of a different sample of Arley coal, but taken from the same mine, was extracted first by chloroform and then by several portions of pyridine, boiling up in each case for a long time until only a trace of soluble matter was obtained. A portion of the residue was then taken and heated in a sealed tube for thirty-four hours at 161–180° C. and the residue from this heated with a fresh portion of pyridine for twenty-four hours at 160–180° C. with the following results, stated on the dry and ash-free substance :—

Some of these fractions were saturated with chlorine, after removal of pyridine, etc., in a current of inert gas at 150° C., and the increase in weight is stated below. Chlorine and hydrochloric acid were removed *in vacuo* over sodium hydroxide.

Increase in weight, per cent., Fraction B, 74.4 ; C 61.4 ; E 55.7 ; F 31 ; H 64.2.

A considerable number of experiments have been made on the action of chlorine at high temperatures. CH_2Cl_2 , CHCl_3 , CCl_4 and C_2Cl_6 in considerable quantities were obtained, but further experiments are being made which will be reported later.

The fact that pyridine dissolves the so-called resin bodies so very slowly and dissolves much more with the slight increase in temperature by the sealed tube method, shows that this is not a case of ordinary solution. The extract once obtained is quite readily soluble in pyridine and gives a thick, viscid, tar-like mass, and that it is not "absorbed" by the insoluble portion of coal is shown by examination of thin sections which show the resinous bands and nodules to be separate from the general matrix.

There appears to be some kind of simplification in the constitution of the constituents which yield the pyridine soluble matter, a process similar to depolymerisation and due to the action of pyridine and heat. This is similar to the behaviour of many ordinary resins which are only soluble in certain solvents after they have been heated at moderately high temperatures for some time. Clark and Wheeler* have shown that the pyridine extract from silkstone coal can be separated into two fractions by the solvent action of chloroform, and the author has found that this is the case with the pyridine extract from Arley coal also. The solution by chloroform is an extremely slow process and requires about two weeks to make the extraction complete. This points to either absorption or depolymerisation.

An interesting point is that this chloroform soluble portion does not appear to be in the original coal as such. There is some portion of Arley coal soluble in chloroform and the quantity seems to vary very much with coal

* Trans. Chem. Soc. 1913, 1705.

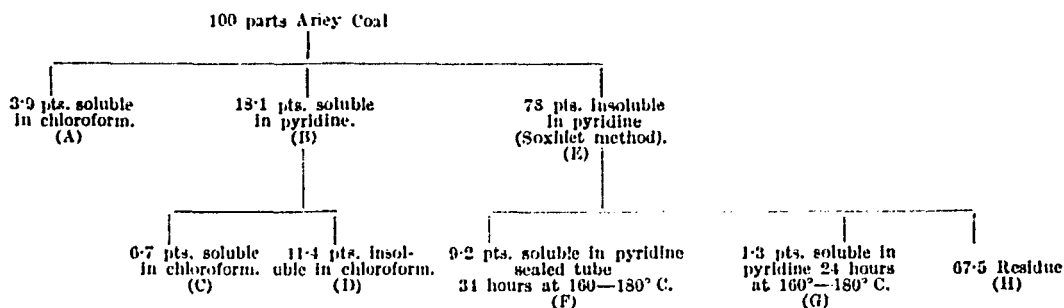


Table showing changes during the separation of silkstone coal fractions by Clark and Wheeler.

All calculated on ash and moisture-free coals.		A	B	C	D		E	F	Average of 12 pts. of E, 8 pts. of F (should equal C).	Diff. + or —
		100 pts. original coal.	80 pts. insoluble in pyridine.	20 pts. soluble in pyridine.	Average of 80 pts. B, 20 pts. C (should equal A).	Diff. + or —	12 pts. C insoluble in CHCl_3	8 pts. C insoluble in CHCl_3		
Proximate Analysis	Volatile matter	30.73	34.06	55.24	39.02	2.20	31.83	77.33	50.06	5.18
	Fixed carbon ..	63.27	65.04	44.76	60.93	2.20	68.12	22.67	49.94	5.18
Ultimate Analysis	Carbon	82.02	80.81	82.39	81.26	1.06	77.32	85.33	80.52	2.37
	Hydrogen	5.58	5.23	7.14	5.61	.03	5.14	7.08	5.01	1.23
	Oxygen	8.45	10.40	0.02	9.04	1.19	14.20	4.56	10.38	3.70
	Nitrogen	1.31	2.14	1.91	2.00	.74	2.07	1.71	1.92	.01
	Sulphur	1.70	1.42	1.44	1.42	.28	1.21	1.32	1.25	.19

even from the same seam. In one experiment it was as much as 3.9 per cent. but generally it did not exceed 1½ per cent. This substance contained no sulphur and no nitrogen and gave on analysis, hydrogen, 8.81 per cent., carbon, 83.92 per cent., oxygen, 7.27 per cent.

The portion dissolved out of the pyridine extract by chloroform was rather more than one-third of the total pyridine extract, and this material contained nitrogen and sulphur as well as carbon, hydrogen, and oxygen.

In the paper by Clark and Wheeler results of extraction of silkstone coal (Altoft's Colliery) by pyridine, and subsequent action of chloroform on the extract obtained, are given with analyses of the various fractions. From their figures it is evident that all fractions contain more nitrogen than the original coal, and it appears on calculation that pyridine amounting to 4 per cent. on the coal taken has been retained by the fractions. Examination of their figures also shows (assuming the analyses to be correct) that in the extraction by pyridine and subsequently by chloroform a considerable quantity of oxygen has been absorbed and some sulphur lost.

These figures show that:—

(1) 100 parts of coal have retained slightly more than 4 per cent. of pyridine.

(2) Oxidation has occurred in both extractions, but especially with chloroform, where the oxygen has increased by nearly 60 per cent.

(3) There is loss of sulphur in both extractions.

It might be gathered from the figures that the absorption of oxygen is an essential feature in the solution of these constituents by pyridine and chloroform, but the fact that more is dissolved by treatment in a sealed tube in absence of air proves that this is not so.

The fact that pyridine is retained by the fractions even after heating in vacuo at 100° for several days has been proved by heating a portion of pyridine extract in a current of nitrogen at 150° C. The gas which came off contained pyridine, and was passed through H₂SO₄, which was distilled later with potash and the distillate titrated. This experiment showed the presence of 3.7 per cent. of pyridine in the material. Later experiments have shown that the portion insoluble in pyridine contained pyridine after heating in vacuo for several days at 100° C. and it has been found much more difficult to remove all the pyridine from the insoluble than from the soluble fractions.

The coking property.

Not every coal gives a satisfactory coke on carbonisation. A coal which will coke must contain a certain minimum quantity of bituminous matter. Coals like anthracite and semi-anthracite do not coke nor do the tertiary coals—lignites and brown coals. The coals selected for making metallurgical coke contain sufficient bituminous matter to fuse on heating to a few degrees above 310° C. The mass of washed coal is converted on heating to a pasty mass, from which, on further heating, the volatile matters distil, leaving a fixed carbonaceous residue which becomes harder and stronger the higher the temperature employed because volatile hydrocarbons are decomposed, with deposition of carbon, in proportion to the temperature of the solid material through which these volatile hydrocarbons have to pass. With very high temperatures the product is hard and will withstand considerable pressure.

It appears that the coking properties of coals must be due to some compounds of C, H, O, N, and S, about which little further is known than that they melt at about 320° C. Anderson and Roberts* showed that coals of the Clyde Basin began to soften at 310° C. and melted fairly completely at 320° C. The best coking coals melted at 317° C. The older coals coked, the newer ones did not.

	Carbon.	Hydrogen.	Oxygen, etc.	Coking power.
Non-coking	82.65	5.55	10.1	3.9
Semi-coking	83.10	5.48	8.98	4.1
Coking	85.41	5.30	7.22	13.5

* See this Journal, 1898, 1013—1020.

It is not possible to tell from the ultimate analysis of a coal whether it will coke, but it is often found possible to say that it will *not* coke. Cases are known of coals of exactly the same ultimate chemical composition some of which coked quite well and the others not at all. An essential part of the process of coking takes place between 250° C. and 400° C. If coking coal is carbonised below 400° C., then powdered and heated to very high temperatures such as are employed in metallurgical coke ovens, there is no sign of sticking together of the particles. It is generally believed that it is the quantity of the so-called resinous constituents in coal which determines its coking or non-coking property. According to Anderson this has been proved to be wrong, but on what evidence is not clear. A study of his papers reveals no facts supporting this conclusion.

Some of the fundamental facts about the coking property are:—

1. The coking property in some coals is destroyed by exposure to air, and even in more strongly coking coals it is sensibly diminished.

2. The coking property in some coals is destroyed, in others weakened and in some not affected by boiling with dilute caustic potash.*

3. Heating in a current of inert gas at 300° C. for several hours destroys the coking power of some coals and weakens it in all coking coals. The strongly coking coals, however, retain sufficient to coke when strongly heated.

Anderson and Roberts conclude, and Professor V. B. Lewes agrees, that on these facts strongly coking coals, in addition to the so-called resin bodies, contain a class of substances which are not soluble in alkali, do not oxidise in warm air and do not decompose or volatilise at 300° C., and that substances of this class melt on strongly heating and yield enough fusing material to form coke. They call the substances of this class the "hydrocarbon bodies." The assumption or deduction of the existence of a class of compounds in coal called hydrocarbons, on such evidence, is not, in the author's view, justifiable and they must be omitted from the constituents of coals. (Hydrocarbons have been found only in mere traces in coals.)

The phenomena described above would be observed if the so-called resin and other bodies on slow heating, etc., decomposed and yielded, amongst other products, a smaller quantity of a substance which was fusible at higher temperature, and this is what the author has found does actually take place. The true coking coals contain sufficient resin-like bodies to yield, after heating at about 300° C., sufficient fusible material to form coke when heated to 320° C. or above. While the feebly coking coals on heating, etc., gave the same kind and proportion of fusible bodies, the quantity was not sufficient to melt or render liquid the whole of the material and so coke could not be formed.

A sample of Arley coal extracted with chloroform gave 1.2 per cent. soluble; on heating another portion of the coal to 230° C. in inert gas for five hours it gave on extraction 1.4 per cent. soluble in chloroform. A third portion, heated for five hours at 270° C., gave on extraction 7.6 per cent. soluble in chloroform. A fourth portion was alternately heated to 330°—340° C. in inert gas, and extracted with chloroform five times; the total time of heating was twenty-two hours, and the total of the chloroform extracts amounted to 8½ per cent. on the original coal. It is evident that a subtle change starts in Arley coal at about 250° C. and at 270° C. it is very marked, although the coal is changed very slightly in appearance and no permanent gas appears to be evolved. Experiments were made to ascertain which part of the coal gave rise to these products soluble in chloroform. Pyridine extract after heating to 340° C. gave 8.2 per cent., and pyridine residue after similar treatment gave 1.6 per cent. It is therefore evident that both constituents give rise to the products.

Nitrogen in coal.

There is evidence to show that nitrogen occurs in coal combined in two or more essentially different ways. A small quantity of the total is given off as ammonia on

* Anderson and Roberts, *loc. cit.*

carbonisation, whilst half of it remains in the coke, indicating that it occurs in coal combined in at least two different ways and probably more.

It has been observed that in some coals the amount of nitrogen estimated by the Kjeldahl method is a mere trace, when a Dumas estimation reveals the fact that there is about 2 per cent. In other coals the two methods show exactly the same amount, showing that the nitrogen is not held in a similar way in all coals. It has been further observed that when some coals are mixed with caustic soda and ignited much less nitrogen remains fixed in the residue after carbonisation than in the residue of the untreated coal, and, on the contrary, it has been observed that other coals, when treated in a similar way with caustic soda, etc., had more of their nitrogen fixed than when heated alone.

Some of the fixed nitrogen can be converted into ammonia by passing hydrogen over the red-hot coke, but the only practical method hitherto devised of increasing the yield of ammonia is to burn the coke while keeping the temperature as low as possible, as in the Mond producers.

The nitrogen which comes off as ammonia on the carbonisation of coal probably exists in side-chain groups whilst that which remains fixed in the coke probably occurs in ring compounds, the ring part being stable at a red heat.

Over twenty years ago R. J. Friswell discovered that by acting on powdered coal with nitric acid of about 50 per cent. strength, a complex organic acid or acids were obtained, which decomposed sodium carbonate with evolution of carbon dioxide. These bodies, which were later called the coal acids by Anderson, are insoluble in water containing much mineral acid but in pure water or dilute alkali or dilute acid they are soluble, giving an ink-like solution. The solid coal acids on heating with zinc dust gave hydrogen, cyanogen, and a small quantity of aqueous distillate, smelling of ammonia and pyridine and containing hydrocyanic acid (Friswell).

Anderson worked on compounds, made from very different kinds of coals by treating with nitric acid, and found that the resulting coal acids had about the same ultimate chemical composition. It seemed probable that the nitric acid oxidised all the side-chains, giving COOH groups attached to a nitrogen ring complex. To test this the author oxidised some Arley coal with fuming sulphuric acid (so as to keep nitrogen containing reagents out of the experiments) and obtained similar compounds to those got by Friswell and by Anderson. The solid purified coal acid was mixed with caustic soda and heated. A gas smelling like charred albumen or bone was obtained, and the same was obtained several times on repeating the experiment with fresh quantities of coal. This would appear to indicate that coal contains nitrogen in the form of a ring complex, which on oxidation with fuming sulphuric acid is converted into a carboxylic acidine.

The old and modern Coalite processes were described by the author. In the modern process the coal is carbonised at about 650° C. with the result that the fuel is not so friable. The yield of sulphate is raised from 12 lb. to 28 lb., the tar is reduced to 18 gallons and the gas increased to 8,500 cubic feet per ton of an average bituminous coal. He also referred to low temperature carbonisation *in vacuo*, and pointed out that as much as 80 to 100 gallons of coal oils were obtainable from certain cannel coals by this process, a considerable portion of which could be converted into petrol (8 to 10 gallons) and a large proportion of the remainder into oils suitable for use in Diesel engines. Another low temperature carbonisation process, viz., the "Del Monte," was briefly mentioned.

None of these processes was intended to replace either gas-works practice or the metallurgical coke ovens, and the author questions whether, in view of the demand for a smokeless fuel and the great advance in the value of petrol and oil suitable for Diesel engines, the modern gas-works practice of obtaining as much gas as possible per ton of coal had not been overdone, and the old lower temperature carbonisation was not more suitable to present needs.

As regards metallurgical coke it was also a question whether this could not be produced in two stages, viz. :—

- (1) Carbonisation at a sufficiently low temperature to preserve the valuable light oils and give rich gas, and
- (2) High temperature carbonisation to give the finished hard coke and poor gas.

Both the gas-works manager and the coke-oven manager could learn from the study of big gob-fires that, under certain conditions, it was not a question of how difficult it was to heat up coal, but how difficult it was to prevent it heating up spontaneously. Also that a gob-fire could give a beautiful hard coke with coal which no existing coke-oven process could coke at all.

Practically any bituminous coal could be coked in favourable circumstances, but ordinary coke-oven processes did not give these favourable conditions.

Meeting held at the University on Wednesday, February 25th, 1914.

PROF. E. C. C. BALY, F.R.S., IN THE CHAIR.

PREDICTION AND INVENTION IN CHEMISTRY.

BY H. E. POTTS, M.Sc., CHARTERED PATENT AGENT.

This paper deals with the antithesis between prediction and invention in chemistry; first, the nature of invention, and second, the possibility of prediction. For this purpose we must consider the manner in which modern chemical technology evolves and differentiate this evolution in order to display two distinct types of factors which contribute to it. One of these types includes continuous improvements such as may result from the exercise of skilled workmanship or good judgment, from the satisfaction of local requirements, or from the dictates of convenience or necessity. The other of these types includes what are denoted "inventions." An invention represents a discontinuous advance, a sudden change, even though it may be a small one. Such a discontinuous technological variation may result from a fortunate accident, from careful experiment, from keen observation, from a happy thought, or from the concentration of an intellect far more powerful than the average. Any of these causes may give birth to an improvement which somehow differs from the other type of improvement arising from skilled workmanship, and we may express this difference by saying that discontinuous improvement is an invention.

Technology may advance by improvements in degree, which are not inventions, and by improvements in kind, which are inventions, but this sentence would give an erroneous impression if read apart from what follows.

An American authority, Professor Robinson, has expressed the difference by saying that an invention involves the exercise of the creative, as opposed to the imitative, faculties of the mind. This is well put, but it does not take us much further, since it calls for a definition of the word "creative."

From the legal point of view an invention is an advance in technology which is capable of forming the subject-matter for a patent. For over a century it has been recognised that the principle upon which the Crown grants patents resembles that of an ordinary contract. The inventor comes forward with an invention and puts the public in full possession of it. In return, the Crown grants him a monopoly of its exercise for the term of fourteen years.

There are certain conditions attached to the contract. If the inventor is to receive a reward he must give the public a real something which was not before in their possession, and that something must be useful to the public. It is not every improvement in technology which can form the subject-matter of a patent, since if this were so industrial advance would be unduly hampered, because people would be prevented from making the slightest modification in what they had been doing previously. For instance, it would have been ridiculous if, by means of the Patent Law, manufacturers could have been prevented from using plantation rubber for the various purposes for which they had previously used Para rubber, even though