Adopted at the stated meeting of the Committee on Science and the Arts, held Wednesday, October 6, 1897, and approved by the Board of Directors of City Trusts.

JOHN BIRKINBINE, *President.*

WM. H. WAHL, *Secretary.*

Countersigned by

JAMES CHRISTIE,

*Chairman of the
Committee on Science and the Arts.*

THE ECONOMETER: A GAS BALANCE FOR INDICATING CONTINUOUSLY THE PROPORTION OF CARBONIC ACID GAS IN THE FLOW OF FURNACE GASES.

Being the report of the Institute, through its Committee on Science and the Arts, investigating the invention of Max Arndt, of Aix-la-Chapelle.

[No. 1,973.]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, September 1, 1897.

The Franklin Institute, of the State of Pennsylvania, for the Promotion of the Mechanic Arts, acting through its Committee on Science and the Arts, investigating the merits of Arndt's Econometer, reports as follows:

The sub-committee appointed to investigate the operation of an instrument for the measurement of carbonic acid gas (CO_2) escaping in the flow of the products of combustion from a steam-boiler furnace, have performed the duty assigned them, and beg to report that:

This instrument is known under trade name of Econometer, and is the invention of Max Arndt, of Aix-la-Chapelle, Germany, by whom it was patented in the United States, October 16, 1894.*

* See U. S. Patent, No. 527,397.

Through Mr. Joseph Wilckes, of New York City, the inventor's American representative, a request has been presented to this Institute for an examination into the merits of the instrument, for the purpose indicated above.

The apparatus consists of a balance beam, carrying at one end a gas vessel, provided with a neck open at the bottom; a gas delivery pipe projecting upward into this gas vessel being fixed and supported in it in such a way that upon the oscillation of the balance beam the gas vessel may move freely up and down without coming in contact with the upward projecting pipe through which the gas flows into the gas vessel.

The gas vessel is balanced by a compensating vessel suspended from the opposite end of the beam, also open at the bottom, and equivalent to the gas vessel in its capacity in conjunction with small weights placed on a pan under the compensating vessel, that the pointer of the beam shall move to zero on the scale when atmospheric air is drawn through the apparatus.

The gas vessel being open at the bottom, so that the pressure within it is always the same as that without, fluctuations of pressure and barometrical readings have not to be considered in the use of this apparatus, likewise fluctuations of temperature do not affect its action, because the gases passing slowly through the apparatus quickly take the temperature prevailing in the narrow gas passages.

The fluctuations which take place in the density of the gases round the fixed pipe in the gas vessel cause up-and-down motions in the latter vessel, which are shown by the pointer on the scale. This pointer is rigidly fixed to the beam so as to follow the movements of the gas balance; it oscillates in front of a divided plate or scale, indicating units of weight by the distance between its dividing lines, or these distances shall in conjunction with the pointer indicate a particular percentage volume of a particular kind of gas in a gaseous mixture. For example, the instrument placed at the disposal of this committee had divisions on its scale for indicating the percentage volume of carbonic acid gas, for the purpose of ascertaining

the percentage of such gas escaping in the products of combustion from a steam-boiler furnace.

Two tubular orifices are provided, one for the inlet, and the other for the outlet of gases, the former connecting by a flexible tube with the vertical fixed pipe in the gas vessel, and the latter by a flexible tube with the cup-shaped vessel situated below the gas vessel. The source of the gas supply is placed in communication with inlet leading to the gas vessel, and a suction apparatus of any suitable kind in communication with outlet from the cup vessel under the gas vessel. A portion of the air present in the casting is first drawn off, that is to say, the air is exhausted by suction to so much of a vacuum as corresponds to the strength of the suction at the cup vessel under the gas vessel. This rarefaction being obtained, the gas to be weighed passes into the gas vessel, filling it, and then out of this vessel into cup vessel below.

The gas balance is enclosed in a casing provided with a glass front for the purpose of observation; this casing is provided with an aperture closable by a plug, upon the removal of which the weights may be adjusted as required. Further, at the top of the casing, there is an aperture filled with cotton-wool for the gradual and continuous admission of atmospheric air thereto. The balance is, therefore, located in a nearly air-tight chamber, with its several parts so arranged that, when the gases to be weighed flow through a vessel forming part of the balance, it may operate without resistance and with greatest sensitiveness.

The determination of the percentage volume of a particular kind of gas contained in a gaseous mixture is only practicable by means of the apparatus when the specific gravity of the gas sought for is different from the specific gravities of the other gases preponderating in the gaseous mixture, but such other gases may be of like specific gravity among themselves. This, for instance, is the case with respect to the smoke gases of steam-generator furnaces, which gases are mainly made up of oxygen, nitrogen, carbonic oxide and carbonic acid. Of these, the first three are of nearly the same specific gravity, approxi-

inating that of atmospheric air = 1. On the other hand, the specific gravity of carbonic acid = 1.52, and is, therefore, about one-half heavier than atmospheric air, and a smoke-gas mixture must consequently be heavier the greater its contents of carbonic acid. With perfect combustion of the carbon contained in the fuel and with the air of combustion measured in a theoretically accurate manner, the carbonic acid of the smoke gases amounts to about 20 per cent. of the total volume, but it is less than this when the air of combustion is supplied in a larger quantity. If now the zero line of the scale has such a position that it coincides with the pointer when only atmospheric air is present in the gas vessel; if, further, the end line or division of the scale has such a position that it coincides with the pointer when atmospheric air mixed with carbonic acid to the extent of 20 per cent. of the total volume as determined by a chemical analysis, is drawn through the gas vessel; and if, further, the scale has twenty corresponding divisions, then the movement of the pointer from one division to another will correspond to the difference in the weight of the gaseous mixture in proportion to the percentage volume of carbonic acid; and accordingly, in the practical use of the apparatus, that is to say, when smoke gases are being conducted through the gas balance, the contents of carbonic acid, as indicated by the pointer in a sufficiently accurate manner for practical purposes, may at any time be read off from the scale direct. If, for instance, the pointer points to the division line marked 12 on the scale, this would indicate that the smoke gases drawn through the vessel contain 12 per cent. in volume of carbonic acid, that is to say, the volume of the latter would amount to 12 per cent. of the whole volume of the smoke-gas mixture.

If the smoke gases of a steam-generator furnace when passing to the chimney have a temperature of 270° C. (or 518° F.) and 12 per cent. of their total volume consists of carbonic acid, the loss of heat amounts only to about 15 per cent.; but if at the same temperature the carbonic acid contents amount, for example, to only 4 per cent. of the volume of the waste gases, this would show a loss of heat of about 45 per cent., due in a great measure to the heating of an excessive quantity of

air for the combustion of the fuel. Hence, it results that the gas balance herein described is of great importance as a controlling apparatus for steam generator and other furnaces and also for obtaining the specific gravity of other gaseous mixtures by direct weighing.

A practical test of this instrument was made by the investigating committee, at the Baldwin Locomotive Works in this city, with the results given in the annexed table. The boiler furnace from which the supply of gas was taken was one in which anthracite coal was used, the boiler was of the Babcock & Wilcox manufacture, and its furnace setting was in no re-

The Arndt "Econometer."

spect different from their ordinary practice. The gas analysis was by Prof. Harry F. Keller, Ph.D., of this city, each analysis was made immediately upon the withdrawal of the samples and at the place where the other tests were being conducted.

These comparative tests satisfied the investigating committee as to the substantial accuracy of this instrument. The recorded variations given in the annexed tables show discrepancies so trifling that, if the econometer were used in the management of steam-boiler furnace fires, no considerable loss would occur by reason of the difference between the

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econometer reading and the chemical analysis. A saving in fuel would result because of a better and more intelligent management of fire and damper, allowing less surplus air to pass through the furnace than would ordinarily be the case.

The "Econometer" works continuously, and shows automatically the percentage of carbonic acid in the gases, thus enabling the fireman to see at all times the more or less favorable conditions of combustion.

The claims made for this instrument have, in the opinion of the investigating committee, been fully substantiated in its presence, and the Franklin Institute therefore awards the Elliott-Cresson Medal to Max Arndt, of Aix-la-Chapelle, Germany.

An appendix accompanies this report, giving some theoretical deductions by Max Arndt, on the subject of partial combustion. Also the record of observations and gas analysis relating to the test at the Baldwin Locomotive Works.

Adopted at the stated meeting of the Committee on Science and the Arts, held Wednesday, October 6, 1897.

JOHN BIRKINBINE, *President.*

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APPENDIX.

The following table, accompanying the description of the "Econometer" furnished your committee, shows the loss of heat and fuel with from 2 to 15 per cent. of carbonic acid gas in the combustion gases:

For coal of medium quality.	If the "Econometer" shows	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Per cent. carbonic acid,
	Then the quantity of air passing through the flues is	9.5	6.3	4.7	3.8	3.2	2.7	2.4	2.1	1.9	1.7	1.6	1.5	1.4	1.3	Times the theoretical requirements.
	With a surplus supply of air of 30 per cent., or about 10.4 cubic metres of necessary air per kilo. of fuel, there will still be a further excess of about	65.6	40.0	27.2	20.0	15.2	11.2	8.8	5.6	4.8	3.2	2.4	1.6	0.8	0.0	Cubic metres of superfluous air, heated to a temperature of usually 270° C.
	And the loss of fuel at 270° C. amounts to	90	60	45	36	30	26	23	20	18	16	15	14	13	12	Per cent.

One kilogram of anthracite coal of medium quality requires theoretically about 8 cubic meters of atmospheric air.

If, for example, in the case of a steam boiler using a medium quality of anthracite, the econometer shows an average of only 3 per cent CO₂ (a case often happening in practice), then the volume of air used for the combustion of a kilogram of coal and the almost equal volume of gaseous smoke is about $8 \times 6.3 = 50.4$ cubic meters reduced to the temperature of 0° C.

If the atmospheric air passes to the grate at a temperature of 20° C., and the combustion gases leave the boiler at 270° C., the difference of temperature amounts to 250° C., then the heat carried away by the chimney gases (which, on an average for each degree centigrade per cubic meter, require 0.32 of a heat unit) amounts to $50.4 \times 250 \times .32 = 4032$ heat units.

Further, if the anthracite coal used has an actual heat value of 7,000 heat units, the loss of heat or fuel loss can be calculated at about

$$\frac{4,032 \times 100}{7,000} = 58 \text{ per cent.}$$

If with the same firing and with a larger supply of air the amount of carbonic acid falls to 2 per cent., the loss amounts at once to $8 \times 9.5 \times 250 \times 0.32 = 6080$ heat units, or about

$$\frac{6,080 \times 100}{7,000} = 87 \text{ per cent. of coal.}$$

RECORD OF TEST OF ECONOMETER AT BALDWIN LOCOMOTIVE WORKS, AUGUST 13, 1897.

Time.	Econom't'r Reading.	Gas Analysis.			Draft M'm.	Memoranda.
		Sample Taken.	Carbonic Acid.	Oxygen.		
P.M.	Per Cent.	P.M.	Per Cent.	Per Cent.		Fired at 2 P.M.
2.04	3'80	2 05	4'02	14'95	7 m.m.	Steam pressure 135 pounds. Fire about 7 inches thick.
2.05	3'80					
2.05½	3'80					
2.06	3'80					
2.06½	4'00					
2.07	4'00					
2.07½	4'00					
2.08	4'10					
2.08½	4'10					
2.09	4'00					
2.09½	4'00					
2.10	4'00					
	3'95 Average.					
2.21	4'70	2.21	4'84	no det.		
2.21½	4'70					
2.22	4'70					
2.22½	4'65					
2.23	4'15					
2.23½	3'40					
2.24	3'15					
2.24½	3'10					
2.25	3'30					
2.25½	3'40					
	3'915 Average.					
2.40	3'80	} 2.43	4'12	15'46	7 m.m.	Fired 2.49 P.M. Steam jet blower on at 2.54 for 5 minutes.
2.40½	3'80					
2.41	3'90					
2.41½	3'90					
2.42	3'90					
2.42½	4'00					
2.43	3'90					
2.43½	3'90					
2.44	3'80					
2.44½	3'80					
2.45	3'70					
2.45½	3'60					
	3'81 Average.					Fired 3 P.M.
3.00	8'00	} 3.03	9'06	10'85	7 m.m.	
3.00½	8'60					
3.01	9'10					
3.01½	9'40					
3.02	9'60					
3.02½	9'70					
3.03	9'00					
3.03½	7'00					
3.04	6'80					
3.04½	7'20					
3.05	8'00					
3.05½	8'60					
3.06	8'90					
3.06½	9'00					
3.07	8'90					
	8'52 Average					

RECORD OF TEST OF ECONOMETER AT BALDWIN LOCOMOTIVE WORKS, AUGUST 13, 1897.

Time.	Econom't'r Reading.	Gas Analysis.			Draft M'm.	Memoranda.
		Sample Taken.	Carbonic Acid.	Oxygen.		
P.M.	Per Cent.	P.M.	Per Cent.	Per Cent.		Blower on 3.15 P.M.
3.23	11.00					
3.23½	11.00					
3.24	10.90					
3.24½	10.80					
3.25	10.50					
3.25½	10.50	} 3.26	10.53	8.38	8 m.m.	Fired 3.26 P.M.
3.26	10.40					
3.26½	10.30					
3.27	10.10					
3.27½	9.80					
3.28	9.70					
3.28½	9.60					
	10.38					
	Average.					
3.40	8.70					
3.40½	8.90					
3.41	8.80					
3.41½	8.70					
3.42	8.40					
3.42½	7.90	} 3.43	6.57	not det.	7 m.m.	Blower off 3.42 P.M. Fired 3.44 P.M.
3.43	6.80					
3.43½	6.00					
3.44	5.50					
3.44½	5.10					
3.45	4.80					
3.45½	4.60					
	7.02					
	Average.					
3.54	4.00					
3.54½	4.00					
3.55	4.00					
3.55½	4.00					
3.56	4.10					
3.56½	4.30	} 3.57	4.36	15.10		
3.57	4.50					
3.57½	4.40					
3.58	3.80					
3.58½	3.30					
3.59	3.00					
3.59½	3.10					
4.00	3.50					
4.00½	4.00					
	3.857					
	Average.					

[NOTE.—The "Econometer" readings inclosed in braces are those taken during the time of drawing the samples for chemical analysis.]