THE USE OF WATER AS A FUEL.

By Dr. George W. Rachel.

The results of certain experiments, made with what has been called the Holland Hydrogen Locomotive, have lately been published in several city papers. They are not only of the highest practical importance, but of great scientific interest, so that it appears entirely proper to discuss them from that aspect in this journal.

The fuel used is naphtha and water; the manner in which combustion is accomplished by a peculiar unique apparatus may be shortly described thus:

The principal feature of this new invention is an iron retort having two compartments, one for naphtha and the other for water. The two fluids are conducted into the two chambers by induct-pipes at one end of the retort, while at the opposite side there are two escape-pipes, through which the vapors of the two substances escape from their respective chambers, where gasification has taken place. The two gases are being mixed by passing into a common receptacle, the manifold, and from there they are distributed through three main pipes to the 352 burners. Of these 44 are placed directly under the (four) retorts, while the balance is arranged under the boiler.

The astonishing results obtained by this ingenious apparatus have been the subject of many discussions in various scientific and industrial journals on both sides of the Atlantic. The attacks have usually been directed against the possibility of making an advantageous use of the hydrogen for the purpose of combustion. The explanation that in the Holland retort the principal source of the tremendous heat produced, is due to the combustion of hydrogen derived from the dissociation of the water vapor, has been supposed to be met by the following statement:

The dissociation of the steam must consume as much heat, as is afterward developed by the combustion of the hydrogen.

It was contended that the principle of the Holland method was entirely wrong, implying an error against the law of the conservation of energy which is the fundamental law of the Universe, and therefore this whole matter must be a delusion.

This objection, which looks plausible enough can be shown to be erroneous, as it is based on a misconception, or rather a misinterpretation of this great law of Nature. The error consists in the wrong application of the word heat; the sentence containing the objection to be correct, must read thus:

The dissociation of the steam must require as much *energy*, as is afterward developed by the combustion of the hydrogen thus obtained. Now, it is a fact, that the energy developed by the combustion of the hydrogen invariably takes the form of heat, but the principle of the correlation of forces which forms the basis of this very law, teaches us that it must not necessarily do so during the process of dissociation. In order to fully expose the misinterpretation of Nature's fundamental law contained in the objection above quoted, we may be allowed a few words on the subject of dissociation.

Prof. H. St. Clair Deville, who first succeeded in an ingeniously contrived apparatus to dissociate water vapor into its elements, hydrogen and oxygen, estimates the temperature required for the purpose at 6000°C, probably even somewhere near 8000°C. Prof. Schroeder van Der Kolk even places it at a still higher figure, viz.: about 10,000°C. But these figures, it must be well understood, refer to the dissociation of water vapor in the absence of any other element. If, on the contrary, the dissociation is induced to take place in the presence of other elements —notably metals—the dissociation temperature is lowered considerably. Thus, for instance, the dissociation is effected in the presence of platinum, at 1700°C; iron filings, 1400°C; silver, 1000°C, instead of 8000°C.

The question is now: How are we account for this? Prof. Deville in a controversy now going on between Prof. Ad. Wurtz and his school, and Berthelot and himself, on this very subject of dissociation, replies to some objections of his adversaries, as follows:*

It is a well-established fact that the dissociation of water-vapor takes place at much lower temperatures in the presence of certain elements. . . . . These and other examples . . . . prove that the development of heat during the formation of a compound body, does not hold any known relation to its dissociation temperature. Evidently the error is very frequently committed in regard to these processes to confound actual and kinetic energy, actual and latent heat."

The relation referred to in this passage, must, however, in the light of the law of "Conservation of Energy" be one of absolute equivalency; the energy expended on one process—dissociation—must under all circumstances be equivalent to the energy developed during the other process—formation of the compound body, *i. e.* in our case water-vapor.

If, therefore, our experiments show that the temperature of dissociation is lowered in the presence of certain elements, we must look for some other form of energy which supplants the amount of heat saved. What force is it that steps in here and plays the role of a dissociating agent in place of the tremendous heat? The answer is obvious, it is *chemical affinity*, for chemical affinity is the only form of energy capable of such intensity of action. Furthermore, chemical affinity is to a certain extent not directly discernible and measurable, as Friedrich Mohr has shown.†

The irrefutable proof for our assertion lies in the fact that there is in the case under consideration, always formed an oxide of the metal employed. We find the molten silver and platinum covered with thin films of their respective oxides while the iron filings show an amount of oxidation which is—as it is in the two former cases—in direct proportion to the quantity of vapor dissociated. The chemical affinity of the glowing and molten metals to the oxygen of the water-vapor being greater than the chemical affinity of hydrogen to oxygen, they appropriate the oxygen of the steam, and, combining with it, form their respective oxides—thus liberating the hydrogen and accomplishing dissociation.

Deville's above-quoted statement, that there is no known relation betweenthe formation—and dissociation-temperatures of compound bodies must be modified, therefore, in the light of the foregoing observations. What he is pleased to call "Kinetic energy" and "latent heat" is actually nothing else than chemical affinity. The position of Wurtz and his followers, by the way, is untenable; they contend that the two temperatures should be equal, (in accordance with the law of the conservation of energy) and meet the often observed fact that these temperatures differ considerably with the assertion that, as theoretically they should not do so, the observations are wrong. Their interpretation of the great principle contains the same error which the objections to the Holland process are suffering from; they insist that the energy which produces dissociation must take the form of heat and heat only, because heat is the only form of energy met with during formation. They forget that such limited application of this great principle is entirely arbitrary and that the only requirement of the law is that of absolute equivalency, while there is no rule as to the kind of energy required.

I have been somewhat elaborate in my remarks on the subject of dissociation, because the conditions under which the dissociation of steam takes place in the Holland process are the exact counterpart to those which have just been dwelled upon. Instead of the metals, the

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*Comptes rendus, 1879.

† Science Vol. I, pg. 244.

carbon of the Naptha-gas reduces the dissociation-temperature.

The fact that under certain conditions carbon has a dissociating action on steam, or—as some put it—carbon may be burned up with watery-vapor, has been known for a long time; the presence of free hydrogen in furnace and generator-gases is due to this circumstance. The difference between the dissociating action of carbon on water-vapor as compared with that of the metals above-mentioned is only one of degree. *The temperature at which it takes place is much lower.*

After a prolonged and careful observation of the phenomena connected with the Naphtha and water-process under consideration, the writer was firmly convinced that the carbon in them plays the role of a dissociating agent, and that the temperature at which its dissociating property asserts itself must be a low one, comparatively speaking. For, in this way only was it possible to account for remarkable results of the HOLLAND heating method.

Unhappily, we were not then acquainted with the experiments presently to be discussed, although the fact privately communicated to us that MR. MOSES FARMER, of Hartford, the well-known philosopher, had found experimentally the temperature at which carbon will dissociate water-vapor to be not much above 900° C., seemed to confirm the position taken.

While our proposal to entrust some able chemist with this investigation was under consideration, we became aware of the fact that the desired experiments had already been made in another quarter of the globe more than a year ago. Thus, fortunately, a doubt of their genuineness, which otherwise might perhaps have been entertained by the opponents of the HOLLAND method, is out of the question.

PROFESSOR ACKERMAN, who is superintendent of the chemical labratory at the *Stockholm School of Mines*, requested one of his assistants, MR. C. G. DAHLERUS, to make some experiments with the view of determining the temperature and other circumstances required for the combustion of carbon with watery vapor. The real aim was to explain the occurrence of free hydrogen in both furnace and generator gases; this fact is, as we said before, well-known to mining engineers.

The apparatus used by DAHLERUS consisted of a tube filled with charcoal, which was heated in a combustion furnace, while steam, generated in a separate boiler, was allowed to pass through it. The temperature was determined by trays of steatite containing pieces of Mayerhofer alloys, with various melting points being introduced into the tube. The gases generated were collected, after having passed through a spiral gas tube in order to condense the steam they contained, and were then analyzed. Every experiment lasted at least two hours before a sample of the gas was taken, the pressure of the steam in the induct pipe being kept as uniform as possible.

The results of these experiments have confirmed the correctness of our position, and have shown that dissociation of watery vapor in the presence of carbon takes place at much lower temperatures than has hitherto been admitted.

MR. DAHLERUS, in giving a table of his results, sums up as follows:

"On examining this table it appears that watery vapor is decomposed at a temperature which is indicated by the alloys as from 450° to 500° C.; *but the temperature may, in fact, not have been higher than* 400° *C., because zinc in the interior of the tube was not fused in any of the first five experiments.*"

It is evident that in the Naphtha and water process the conditions, under which the dissociating action of carbon on water vapor takes place, are much more favorable to it than those obtained in the apparatus used by DALHERUS for his experiments.

In the first place the action of carbon in the latter gentleman's apparatus could not but be of a very slow nature, the surface only of the glowing charcoal in the tube being enabled to gasify and act chemically on the steam surrounding the pieces of it. In the process under consideration, however, the whole of the carbon of the naphtha is in gaseous condition and by diffusion the vapor is acted upon simultaneously at every point. Furthermore, this very gasification of the carbon requires a definite, not inconsiderable, amount of heat which in DAHLERUS' apparatus has to be supplied by the steam itself, this being the only substance admitted into the presence of the charcoal in the tube. In the new process, on the contrary, this gasification is effected before the carbon-compounds of the naphtha are mingled with the steam and no loss is therefore experienced in in this direction. But, aside from these details—for the combustion-furnace will probably furnish the wanting heat—the highly important fact is established by these experiments that chemical affinity does, in this dissociation process, supplant heat for the greater part. And, considering the great advantages, above detailed, of the HOLLAND process over these experiments, we are justified in assuming the lowest temperature, found sufficient by DAHLERUS in five of his experiments, as entirely sufficient in the HOLLAND process also. *Instead of* 8000° C., *therefore being required for the dissociation of water, it will here take place at* 400° C.

A gain therefore of, say for convenience's sake, nineteen twentieths is effected; for every particle of hydrogen thus dissociated and liberated, at 400° C., will develope its full 8000° C., on combustion with oxygen, *i. e.*, on being burned up by the draft air. And this saving is accomplished by the supplanting of heat with chemical affinity, the latter performing the greatest part of the work of dissociation.

Nor is this all!

It is necessary to state here that DAHLERUS in pursuing his work had in view also, the preparation of *water gas*, which has been introduced into Sweden by PROF. TORREL, who was one of the commissioners from that country to the Centennial Exhibition at Philadelphia. He therefore endeavored to find the most favorable condition for the production of *water gas*, a mixture of hydrogen and carbonic oxide which is known in this country under various names (*e.g.* STRONG, LOWE and others.)

This explains the following sentence in the conclusions he draws from his results:

"Further we see that the greater the excess of watery vapor the richer in carbonic acid are the gases; or, in other words, *that carbonic oxide is very easily burned to carbonic acid by means of watery vapor*, and that the content of carbonic oxide is increased both by a lessened excess of watery vapor and by the raising of the temperature. The best gas is thus obtained by raising the temperature as high as possible and by a moderate supply of steam."

What DAHLERUS refers to as *the best gas* must be understood to be *water gas* in the accepted sense of the word, viz.: A mixture of carbonic oxide with hydrogen. It is for this reason that he advises the use of a limited supply of steam only; for, if there is an unlimited supply of steam, the dissociation of the same continues and the carbon, instead of being confined to its first stage of oxidation (to carbonic oxide), completes this process and is burned up to carbonic acid. Although the result is by these means a gas much richer in hydrogen—in fact twice as rich—this is not what the manufacturer of water-gas wants. He wants a product that may be used for illumination as well as for heating purposes and, therefore, he does not want an almost pure hydrogen-flame—which is non-luminous, as is well known. But with the HOLLAND process this is quite different; here the manufacture of illuminating gas is effected in a separate automatic arrangement which does not concern us here now. In the process under consideration, therefore, the heating quality of the gases is the only consideration. This, the more so, since there is here no separate generator from which the gases therein manufactured are led away in pipes to the heating-place. The generator, *i. e.* the HOLLAND retort is at the heating-place, in the fire-box of the locomotive, and the full effect of the carbon combustion is therefore obtained in both cases, whether the dissociation of the steam takes place to furnish oxygen for the first stage of this combustion only or whether the dissociation is accomplished so as to burn up the carbon completely with oxygen derived from the dissociated water-vapor. But there is this great difference: If the carbon derives all the oxygen necessary for its complete conversion into carbonic acid from the dissociation of the steam, there will be twice as much hydrogen liberated as against its conversion into carbonic oxide only, as will be seen from the following statement of the two cases by DAHLERUS:

"When watery vapor burns carbon to carbonic oxide, there are formed from two volumes of watery vapor and one volume of carbon two volumes of carbonic oxide and two volumes of hydrogen; further, when carbon is burned by watery vapor to carbonic acid, there are formed from one volume of carbon and four volumes of watery vapor, two volumes of carbonic acid and four volumes of hydrogen. Consequently the volume of hydrogen in the gases is equal to the volume of carbonic oxide and double that of the volume of carbonic acid."

In connection with these important relations I must, in conclusion, refer to the results of numerous experiments, made with the HOLLAND process, which can only be fully and satisfactorily explained in the light of the previous discussion. They are certainly a most remarkable series of experiments, never before equalled or excelled; the results accomplished by the Naphtha and water process have startled all experts and scientists who have witnessed them, while those who have not seen their actual performance reluctantly admit their genuineness. Yet they are absolute facts, and the possibilities which they have in store are greater than anything that has as yet been reported.

In starting the fire under the boiler of this locomotive, it must be stated, there is first lighted a small tank filled with naphtha, which is placed under one of the retorts in the fire-box. As soon as this retort is thereby sufficiently heated to gasify the naphtha, naphtha-gas is burned under all the retorts, and water admitted into them to be converted into steam. When both naphtha and water are thus gasified, their gases are jointly admitted to all the burners under the whole length of the boiler, and the generation of steam now begins in earnest. As soon as feasible, steam from the boiler is introduced into the retorts instead of water, so that after this period the naphtha only has to be gasified in the retorts.

I now give one of Mr. CONANT'S tables in full, containing the results of an experiment he witnessed on April 29th:

LIGHTED AT 10:05 A. M. GAS STARTED AT 10:35.

Steam, Pounds.	Time, M.	Naptha, Gall.	Naptha, Per Lb. Gall.	Naptha, Per Min Gall.	TOTALS.	
					Gall.	H. M.
10	69½	5.62	.56	.08	5.62	1 09½
20	15	3.83	.40	.27	9.45	1 24½
30	18½	2.7	.29	.15	12.35	1 43
40	9	2.41	.24	.27	14.76	1 52
50	8	2.14	.21	.27	16.9	2 00
60	7	2.14	.21	.30	19.04	2 07
70	5	1.61	.16	.32	20.65	2 12
80	3½	1.07	.10	.30	21.72	2 15½
90	4½	1.07	.10	.24	22.79	2 20
100	4	1.07	.10	.27	23.86	2 24
110	4	1.07	.10	.27	24.93	2 28
120	4	1.07	.10	.27	26.00	2 32
Engine started out—safety valve blowing—oil disturbed and no record.						
133	5	----	----	----	----	----

Pop valve blowing av. 33 sec., with 32 sec. intervals. No right of way and no run.

The puzzling fact that the higher the temperature and the steam-pressure rise, the less naphtha is burned, would be absolutely inexplicable if it was not for the relations alluded to in the foregoing observations. Up to 60 or 70 pounds of steam-pressure in the boiler the consumption of naphtha averages 2.14 gals. for every ten pounds of pressure added, while above these figures, it averages only 1.07 gals.—just one-half of the former quantity—for every additional 10 pounds. We know what that means. It means that there is an evident supplanting of the naphtha by some other much more powerful heating agent; the naphtha in this process unmistakably plays a subordinate role, as far as the heating is concerned. We know its task. It dissociates the water and thereby liberates its hydrogen; it is the latter that furnishes the bulk of the caloric energy developed. During the earlier stages, when the steam-pressure is yet comparatively low, the quantity of steam introduced into the retorts is limited and the carbon therefore is burned up to carbonic oxide only by dissociated oxygen; as soon, however, as the steam-pressure rises above a certain point the quantity of steam introduced is very soon sufficient to furnish all the oxygen necessary for the complete combustion of the carbon of the naphtha to carbonic acid. Thus, we are enabled by a correct interpretation of Nature's laws to explain fully and satisfactorily the paradoxical fact that the greater the heat, the less the consumption of oil. We know that instead of two volumes of hydrogen in the first, we must have four in the second case.

There is one other point which I may probably feel called upon to treat of, viz.: the utter invisibility of this tremendous fire. For the present the above will suffice.

DR. GÜNTHERS ICHTHYOLOGY.*

Less than a century ago the last edition of the Systema Naturæ of Linnæus, published in 1766, was taken as the basis and text of essentially a new compilation by Johann Friedrich Gmelin, and among the species admitted by Linnæus were intercalated those subsequently added by others to the system. There were very many duplications arising from the imperfect acquaintance of the compiler with his subject, but nevertheless, all told, only 826 species of fishes were named. There are now known, in round numbers, nearly ten thousand species. In the interval between the compilations of Gmelin and the present were published works of a like nature, by Walbaum, Lacépède, Bloch, Schneider, and Shaw. These were all finished before 1804, and were all of very little value. For considerably more than half a century no other descriptive general enumeration of fishes was completed. Meanwhile, from 1828 to 1849, Cuvier and Valenciennes gave to Ichthyology 22 volumes of a work designed to be a general natural history of fishes, but this was never finished. At last, in 1859, was commenced and in 1870 brought to an end, a work purporting to enumerate all the species of fishes known to the dates of publication, by Dr. Albert Günther, under the auspices of the British Museum. For this contribution the scientific world was laid under great obligations to the author as well as publisher. It was a compilation requiring considerable skill and acquaintance with the literature, and the work may be said to have been moderately well performed. Its author followed the outlines of classification proposed many years before by the illustrious Johannes Müller. On the whole this was the best course, perhaps, to be taken at the time. In 1861, however, he gave a systematic re-arrangement of the Acanthopterygian families, which was above all characterized by an excessive valuation placed on very trivial charac-

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* An introduction to the study of fishes. By Albert C. L. G. Günther. Edinburgh: Adam and Charles Black. 1880.