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Preliminary Draft

EXPERIENCES WITH THE APPLICATION OF HYDROGEN PEROXIDE FOR PRODUCTION OF POWER

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Hydrogen peroxide as a source of power is widely known and many details of its application have been published. There seems to be, however, some doubt in some people's minds about the safety of its application. It is the intention of this report to fill this gap, as far as it is possible from memory, and to give a true account of events, mishaps, and accidents in the course of the development of hydrogen peroxide as a source of power, in so far as this work has been done in Germany before and during the last war.

Searching for means to drive a submarine at much higher speeds than the conventional 6 or 8 knots, submerged, it seemed to me that hydrogen peroxide must be especially attractive. I proposed in a letter to the Electro-Chemical Works at Munich, dated April, 1933, the use of hydrogen peroxide for the above mentioned purpose and asked the usual questions about stability, explosivity, concentration, etc. The answer, on the whole, was encouraging, except that only 60% strength could be offered at the beginning. Decomposition tests at atmospheric pressure were started soon. The results showed increasing promise as the strength of the solution and the decomposition pressure was gradually increased.

Soon the German Naval Command became interested in the matter, but first, insisted on making detonation tests before hydrogen peroxide was used in engines. These tests were carried out by a Chemical State Institute at Berlin. A small quantity of 80% hydrogen peroxide was put in a strong solid lead cylinder and was exploded with a strong detonator, $Pb(N_3)_2$. No appreciable enlargement of the hole was measured, as compared with applying the same detonator to water. Consequently, hydrogen peroxide was considered to be nondetonable up to 80 or 82% strength.

In a second series of tests carried out by the same Institute, hydrogen peroxide (80%) was decomposed in an extremely strong vessel made from 18-8 steel by injection of various quantities of permanganate solution to determine the effect of high pressure on the decomposition. I recall the results only vaguely and do not recall any figures, but I know for sure that under certain pressure conditions and with a certain concentration of catalyst, the decomposition came to a standstill. There was a strong indication that high pressure did not accelerate the decomposition, but that it was actually retarded as had been predicted by an expert. This effect, as well as the non-detonability, was considered to be an important basic property of hydrogen peroxide, if it were to be used for the Armed Forces.

At about the same time, the first somewhat crude decomposition tests with 80% hydrogen peroxide solution were made at pressures up to about 450 lbs. with a thruput of approximately 5#/sec. After the encouraging results of this period of predevelopment and research, I founded my own engineering firm on July 1, 1935. The real development of engines and rockets started after this date.

It was about this time, however, that a very serious accident occurred to several physicists who tried to develop an H_2O_2 monofuel. These men were in the service of the German Army Command. They used a solution of hydrogen peroxide (80%) and alcohol in stoichiometric mixture. The solution seemed to be stable, and 100 lbs. of it had been carried in a glass flask over 400 miles in an automobile to its destination. A test apparatus had been built consisting of a pressure vessel, pipes, check valves, and a combustion chamber, made of 18-8 stainless steel. The whole apparatus, including the pressure vessel, detonated soon after ignition. Armoured plates were pierced by fragments and three persons were killed.

Research tests with hydrogen peroxide-alcohol solutions, which should have been carried out, were subsequently made, and the limits of detonability were established. However, we never used any hydrogen peroxide-fuel solutions for any of our rockets or engines, but we did make decomposition tests with "nondetonable" solutions using a solid surface catalyst and found the expected increase in temperature from approximately 450°C for an 80% hydrogen peroxide solution to approximately 700° for the hydrogen peroxide-water-alcohol solution. The accident mentioned above did not, however, retard our work. On the contrary, during the period from 1936 to the outbreak of World War II in 1939, hydrogen peroxide was firmly established as a source of power for military purposes in cases where air was not available or great power or thrust had to be produced for a short period of time. No further accidents occurred during this period.

The major achievements may be listed as follows:

By the end of 1936, about 1000 kilogram thrust had been developed. Shortly after, 4000 brake-horsepower was measured on a gas turbine plant which had previously been developed and converted into an hydrogen peroxide power plant. In each case, permanganate was used as a catalyst with some alkali, either in solution with water or in paste form. Soon a great number of applications branched out from these principal tests.

The first flight with a liquid propellant took place in February, 1937, with 100 kilograms thrust. Later in that year and during 1938, a great number of flight tests were made with A.T.O.'s at 300 to 500 kilograms thrust with land

and sea planes without any accidents whatsoever. All of these were monofuel devices working with 80% hydrogen peroxide. A number of unguided missiles were tested, among them a midget prototype of the V-2 which climbed up to 18 kilometers height and broke through the sound barrier. Rocket propelled depth charges were thrown over 200 meter distance and sea mines, dropped from an airplane, were decelerated so that they fell gently into the sea. During the summer of 1939, the first airplane, propelled solely by a controllable rocket took off (Heinkel 178). The first torpedoes were launched just at the outbreak of the war. In this case, the propulsion engine was used with a dual fuel system, kerosene, and hydrogen peroxide. A single cylinder, 30 Hp, diesel engine was run for 1000 hours on decomposed hydrogen peroxide vapor as a monofuel. Later, a 300 Hp submarine diesel engine was tested in the same way. The accumulation of oxygen in the crank case had to be watched and could be avoided by blowing cooled fuel exhaust gases through it.

Though no major or fatal accidents can be reported during this period, there were, of course, a number of technical failures. None, however, during a flight. During shop tests, we had accidental explosions and fortunately, also, a great deal of luck. Some of these accidents may seem to be of minor importance, but I shall try to report what I remember.

It happened, for instance, that one of my co-workers caught a 2" jet of 80% hydrogen peroxide right in his face. He was thoroughly rinsed with water immediately thereafter. His face became white and swollen, and he could not open his eyelids. He was running some fever for a few days, but his eyesight was entirely unharmed. He recovered very quickly, and no traces were left on his face. Droplets of liquid catalyst, especially those containing alkali, were more feared than hydrogen peroxide, especially the affect on the eyes. However, no long-lasting aftereffects occurred from alkali either. Slight burns occurred frequently, as the proper clothing had not yet been developed. It was made a rule always to have water running in the test stands. An accident which could have been fatal occurred when I tried to separate the mercury column of a pressurized flow meter from hydrogen peroxide by acetylene tetra-bromide, because the use of membranes had given us a great deal of trouble in getting correct measurements. The liquids did not mix, but the contact on the surface was sufficient to cause an explosion of the strong aluminum alloy pressure vessel of approximately 1/2 gal. capacity. The windows were blown out, but no one was hurt, although the explosion occurred about 20" above my head. Looking back on this experiment, the whole undertaking was rather foolish. However, it took a few more incidents to show fully the potential danger of solutions and mixtures of organic compounds with hydrogen peroxide.

There was, for example, the hydrogen peroxide pump used for the 4000 Hp. marine power plant. The entire pump had been made from 18-8 stainless steel. It happened that the stuffing box, packed and greased in the conventional way, blew out several times. Each time, it had been too tight and became too hot. Small quantities of hydrogen peroxide had reacted with the hydrocarbons of the grease. The casing had not been destroyed, but the screws were broken. Later, a grease was developed of paraffin and talcum which gave no trouble when it was applied. In addition, dynamic seals and Buna rubber sealing rings were developed.

Tests were made to ignite hydrogen peroxide and kerosene in a torpedo combustion chamber, This caused, on one occasion, a fairly heavy explosion in the test cell, so that we stuck to the previously developed catalytic ignition which had never given us any trouble before or after. This catalytic ignition was later improved by using self-igniting fuel (hydrazine-hydrate) plus alcohol in solution.

An aluminum pressure vessel (1500 psi) exploded one night. It had been left filled (approximately 5 gallons) over night. For some reason, the test could not be made that previous day. It was found later that the aluminum alloy contained copper. Similar events occurred later, occasionally, if small quantities of hydrogen peroxide were left in the container after a test. Sometimes the hydrogen peroxide decomposed without any explosion, sometimes it was possible to cool the vessel off with a jet of water.

Tests were made to heat a pressure vessel filled with hydrogen peroxide over an open fire. The vessel exploded as soon as the vapor pressure was high enough in the same way as a water and steam filled vessel exploded. No additional effect was noted. This test was made because a 10 ton truck, loaded with H_2O_2 filled aluminum containers, had run into a tree, after the driver had fallen asleep, and caught fire. The fire was soon under control, and no explosion occurred. Over a 10 year period, thousands of tons of hydrogen peroxide were transported, at first by trucks and later by rail in special cars, without accidents, except for the above incident.

Storage facilities were still in the development stage during this period. The material of the tanks was pure aluminum in most cases. It was tried, for instance, to coat the inside of the containers with paraffin and hard polyvinyl chloride, but unprotected aluminum proved to be satisfactory, if kept clean. At the same time, the stabilizers were improved and finally a purer product was made by dual distillation. In the few instances I recall, when a large storage tank started to show an elevated temperature, which is invariably connected with decomposition and which occurs very slowly in large tanks, the process was brought to a halt temporarily by acid additions. If the quantity of H_2O_2 was large enough, it was sent back to the producer and redistilled. In most cases, however, it was mixed with higher percent hydrogen peroxide and immediately used for tests.

The last period, during the war years, saw not only a still further increase of development work, but also the beginning of mass production of hardware by various firms, other than my own. Drawings and a fair number of prototypes had to be prepared and made by my firm. This added another angle to our work and there was no way to avoid this. So the number of plants increased from one to five and the number of employees from approximately 500 to over 4000 at the end of the war. Two of the plants were assigned to development work and the three smaller ones to the production of prototypes. Also, three permanent test bases had to be built, manned, and equipped; one for submarines, one for torpedoes, and one for launching ramps. Groups of field service engineers were located at half a dozen other places. Hydrogen peroxide was to be found everywhere. If the safety of its application had been seriously questioned at any time, it would not have been so widely used. However, the war years did not pass entirely without accidents, as will be described later.

In general, dual fuel (combustion) propulsion units came more and more into the foreground and with it self-igniting fuel. However, during the first one or two years there were some exceptions. The 500 Kg. monofuel A.T.O. unit was in mass production, when the war began. The Heinkel III and Junkers 88 bombers were equipped with ATO units. Many thousands of the rockets were produced and tested using only air and water to simulate the proportioning of the H_2O_2 and permanganate solutions. It was perfectly safe to make the first actual thrust run with hydrogen peroxide during an actual takeoff. The A.T.O.'s were then parachuted and reused up to 60 times, which was, however, above average because there was not that much need. Altogether, there have been thousands of takeoffs from about one dozen different air bases in Europe and later in Russia. Towards the end of the war, they were used less and less, and, finally, only for special purposes, for instance, for reconnaisance. In 1940 there were two or three reports of failures. In every case, one of the two devices failed to work and the planes crashed. (The pilot had lost control, because he could not counteract the momentum.) In each case, the cause was found in the electric switching device which had failed. At no time was the use of hydrogen peroxide for A.T.O.'s considered to be dangerous. The only other accident which occurred, to my knowledge, happened shortly before the war, when a Heinkel airplane took off in an attempt to break the world long-distance record. It was equipped with four 500 Kg. A.T.O.'s. During takeoff, the undercarriage broke down. The two A.T.O. devices in use took off after the crash, while the two other remained filled and ready under the wing. There was no fire or explosion. The crew was unhurt. This accident shows that hydrogen peroxide does not add to the hazards of flying.

Just before the self-igniting fuel was ready for application, we developed and built prototypes of a 1000/1500 Kg A.T.O., which worked on hydrogen peroxide, liquid catalyst, and gasoline, i.e. with full combustion plus decomposition. The unit could be shut down at any time, which could not be done with the previously described A.T.O.'s. The fuel was ignited and combustion maintained by a constant flow of a liquid catalyst. This device was never used in the field, but at many occasions for flight tests. For instance, a guided missile (Enzian) was propelled by it and four of them helped to get the newly developed Ju 287 jet engined bomber off the ground. Four 1000 Kg A.T.O.'s were used for additional thrust. Some of these devices were taken to England after the war where one of them was tested and caused a fatal explosion in which our former, very able, designer, Dr. Schmidt, and two Englishmen were killed. In this case, I would prefer to refrain from any comment, because the fatal test was not made under my jurisdiction. As usual, in most fatal accidents, several unfavorable factors worked together to cause the death of several people. It must, however, be admitted that this type of rocket with three different fluids, which had to be controlled with the right sequence, was more complicated, less reliable, and required more skilled personnel, than the rockets developed previously and later. This device also was electrically started and controlled. About 1000 actual laboratory and flight tests were made, safely, before this accident occurred.

The lesson again is not to rely on electric devices and to choose a mechanical device whenever possible. We had been taught similar lessons, though none resulted in a loss of life, in the case of the launching ramps, in which the authorities finally agreed to a mechanical trigger instead of an electrical device. I blame the gadget mindedness of modern engineers for a lot of avoidable trouble. In other words, when a group of highly-trained engineering specialists is set to work on the development of an engine, everybody trying to do his best, care has to be taken that the final result is simple and reliable.

The development and application of the fully controllable "cold" and "hot" rocket engines for the Messerschmidtt 163 A and B, with up to 5000 lbs. thrust, never, to my knowledge, caused any serious accidents. Mechanical troubles were surprisingly rare for such a new and powerful engine. There may have been a fire after a crash landing, but I do not recall any. There were, altogether, several thousand flights.

During the development and during numerous field applications of the launching ramps, no accidents occurred except for those mentioned above with the switch. Several of our engineers were assigned permanently to the staff of the V-1 regiment as trouble shooters. The men usually stood unprotected close to the ramp, when in operation, like firing a gun. About 200 lbs. of H_2O_2 were decomposed in one second.

In connection with the torpedo development, I can report about two accidents. One not very heavy explosion occurred while the torpedo was still inside the tube. Several men were injured, though not fatally. I do not recall the exact cause, but it was easily corrected and never happened again. However, a second explosion, which caused the death of three men, happened inside a torpedo which had been salvaged after it had been lying on the sea bottom for at least one month. As soon as the men started to dismantle it, an explosion occurred, probably of a mixture of kerosene and hydrogen peroxide. I considered that the development of a torpedo engine was a most difficult task, because of restricted space, the high performance requirements, switching the unit off and on, and the storage of relatively small quantities of reactants over a long period of time at elevated temperatures. By far the best results were obtained with a bipropellant torpedo using approximately 50% hydrogen peroxide and 50% hydrazene-hydrate solution. This torpedo, however, was developed for aircraft only. The number of failures during the torpedo development was considerably greater than in other applications. I believe that the cycle should be simplified and the mechanical requirements reduced. Even so, it may be difficult to make the hydrogen peroxide propulsion system a success in this field.

However, the situation during the 10 year period of the development of submarine engines was entirely different. In this engine, the 80% H_2O_2 was first decomposed into a harmless steam and oxygen gas, which was then combined with fuel oil in a burner. Until a reliable solid catalyst was developed, the start of the decomposition had to be watched and any accumulation of liquid avoided. On one occasion, such an accumulation, followed by a sudden decomposition, caused the handhole of the decomposition chamber to be blown out, without fatal consequences, because the operators were at all times outside of the engine room.

On another occasion, a fire was started by a leaking hydrogen peroxide bag due to the fact that the steel compartments were, by mistake, painted with a mercury paint. This occurred while the submarine was in dry dock and while there was no seawater around this bag. The reaction was rather violent. The hydrogen peroxide started to burn the bag. The fire was quickly extinguished by flooding the dock. The first test submarine of approximately 80 tons displacement was equipped with a 2500 Hp. turbine working on H_2O_2 vapor only. After the submarine was considered fit for sea trials, 6-1/2 knots were achieved, submerged. No serious troubles were encountered during the lifetime of this submarine, although a great number of changes and improvements, especially in the storage and piping system for hydrogen peroxide, had to be made. The catalyst at that time, 1940 and 1941, was still unsatisfactory. Several times, a fire started after the turbine had warmed up, caused by leaking vapor through the glands of the turbine igniting the lube oil of the bearings. Great pains were taken to avoid any hydrogen peroxide leaking into the operators' compartment. In spite of this, it happened that a small quantity of hydrogen peroxide leaked into the operators' compartment and started to slowly decompose in the bilge. The atmosphere resulting from the decomposing hydrogen peroxide became unbearable for the crew. The submarine had to be surfaced quickly and was nearly lost due to further mistakes being made. The piping of the leaking gauge was changed and no further mishaps occurred. During 1941 alone, 80 sea trials were made with at least 1000 tons of hydrogen peroxide being used and with the general result that it was acknowledged that hydrogen peroxide could be used on ships and that it was possible to handle and control the submarine at speeds up to 26-1/2 knots, submerged.

For the full-scale tests and training purposes, 300 ton submarines were built and completed in November and December 1943 and handed over to the German

Navy in December, 1944. After the tests and the necessary changes had been completed, the naval crews were trained. These submarines carried approximately 45 tons of hydrogen peroxide and developed 4500 Hp. using two turbines on one shaft. During 1944, altogether, about 200 sea trials were made and several thousand tons of hydrogen peroxide were used. During 1945, several more submarines of this type were completed and the war ended just when some of them had completed their tests. Nothing can be reported which would in any way have cast doubt on the usefulness of hydrogen peroxide for submarines and consequently, the submarine building program of the German Navy included predominantly a great number of hydrogen peroxide driven boats with 7500 shaft horsepower.

Other tests which might be of some interest were carried out with incendiary bombs, explosive bombs, and 500 kilograms of hexogen (a powerful new explosive) upon both small and large storage tanks filled with 82% hydrogen peroxide (maximum 5 tons of H_2O_2). With the incendiary bombs, which included one phosphorus-gasoline bomb, no great effect was found on the stored hydrogen peroxide. Decomposition, if there was any, came to a standstill after a short while.

A 200 lb. English bomb exploded in the center of a 5 ton storage tank gave no additional effect as compared with an explosion in a water-filled tank. However, it was the general belief that in the case of using 500 kilograms of hexogen, there was some additional affect caused by thermal decomposition of hydrogen peroxide. It might be added here that numerous tests were made with torpedo hulls in which hydrogen peroxide, kerosene, igniter fuel, and feed water had been stored in various arrangements. Rifle shots and explosive ammunition was fired at those hulls. The safest arrangement was that one where the diluent water surrounded the H_2O_2 and the kerosene.

Finally, it may be of interest to make the following statement: "Of all devices finally accepted and introduced into the German Armed Forces, there was no case where any accident was attributed to the use of hydrogen peroxide or where hydrogen peroxide might have aggravated and otherwise caused accidents."

The following devices had been accepted and were in use either for training or in the field and handled by the troops alone:

1. A 500 Kg. A.T.O. H_2O_2 monofuel unit. Several thousand of these units were built.

2. A 300 Kg. thrust, rocket propulsion unit for guided missiles was built at least 1000 times.

3. A bipropellant 1000 to 1500 Kg. A.T.O. Several hundred units were built, but used for tests only.

4. A catapult with hydrogen peroxide propulsion unit (decomposition only) for launching the V-1's. Several hundred of these units were built and used thousands of times.

5. Controllable propulsion of a 750 Kg. thrust unit for the Messerschmidtt 263.

6. Rocket training airplane and the controllable power plant of up to 2000 Kg. thrust for the Messerschmidtt 263 B. Several hundred of these units were built and used thousands of times in the field.

7. Altogether, up to the end of the war, 7 submarines of 300 to 330 tons were accepted by the German Navy. These were considered to be developed beyond the test stage. It can be

safely assumed that hydrogen peroxide has been applied more than 10,000 times by the services, during which time no accidents were reported to have been caused by the application of this propellant.

The following slides give a survey of rockets and power plants developed between 1935 and 1945 which reached the stage of perfection or might be otherwise of interest. (A verbal explanation will be given.)

HW:pll
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