

STRUCTURE AND COMBUSTION OF MAGNEGASESTM

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Abstract

In this paper, we study the structure and combustion of magnegasesTM (Patented and International Patents Pending), new clean fuels developed by one of us (R.M.S.) [1], which are produced as byproducts of recycling nonradioactive liquid feedstock such as antifreeze waste, engine oil waste, town sewage, crude oil, etc., and generally vary with the liquid used for their production. A new technology, called PlasmaArcFlowTM, flows the waste through a submerged electric arc between conventional electrodes. The arc decomposes the liquid molecules into their atomic constituents, and forms a plasma in the immediate vicinity of the electrodes at about 10,000° F. The technology then moves the plasma away from the electrodes, and controls its recombination into environmentally acceptable fuels. In fact, the exhaust of magnegases show: absence of carcinogenic or other toxic substances; breathable oxygen up 14%; and carbon dioxide down to 0.01%. The new fuels possess a new chemical structure first identified by one of us (R.M.S.), which is characterized by clusters of ordinary

molecules and atoms under a new bond of electromagnetic nature. These clusters constitute a new chemical species different than the conventional molecules, since they are stable at ordinary conditions while exhibiting no infrared signature (other than those of conventional molecular constituents), thus confirming that the bond is not of valence type. In particular, the bonding due to the magnetic polarization of the orbitals, from space to toroidal distributions, have resulted to be dominant over electric effects. For this reason the new chemical species is called "Santilli's electromagnecules" or "magnecules".

In this paper we study the novel magnecular structure of magnegasesTM, and confirm that, when the original waste is of fossil or organic type, magnecules are essentially constituted by conventional molecules H_2 , CO , CO_2 , H_2O , plus individual atoms of H , O , and C , as well as radicals such as HO , CH and $C-O$ in single valence bond, all these constituents being bonded together by strong magnetic fields originating from the toroidal polarization of the orbits of valence and other electrons. We then present, apparently for the first time, an estimate of the binding energy of magnecules. We also study the combustion of magnegases produced from liquid feedstock of fossil origin, and show that it is fundamentally different than the combustion of any other fuel. Conventional fuels are constituted by conventional molecules, and generally burn according to only one dominant thermochemical reaction. In this sense, the combustion of conventional fuels can be conceived as the firing of a "single stage rocket". MagnegasesTM are instead constituted by conventional molecules bonded into the new magneclusters, thus having a multi-stage structure, and they generally have a sequence of dominant thermochemical reactions. In this sense, the combustion of magnegases can be referred to the firing of a "multi-stage rocket", with different fuels in different stages. In this paper we study, apparently for the first time, the primary chemical reactions in the combustion of magnegases of fossil origin. Our main conclusion is that fuels synthesized under intense electric and magnetic fields can indeed release energy in amounts much bigger than those predicted by conventional chemical reactions. Since, in addition, the new fuels can be produced everywhere, and have environmentally acceptable exhausts, magnegases offer serious possibilities to satisfy our ever increasing energy needs, as well as to contain the alarming environmental problems caused by fossil fuels.

1 Introduction

According to official data by recent U.S. Department of Energy (DOE) release, about 74 millions barrels of fossil oil, corresponding to about four billions gallons of gasoline, are consumed in our planet per day in an estimated number of half a billion cars, one million trucks, one hundred thousand planes, plus industrial, agricultural, and military uses. The combustion of such an enormous amount of fossil fuel per day has caused increasingly alarming environmental problems, such as:

- 1) Measurable emission in our atmosphere of the largest amount of carcinogenic and other toxic substances;
 - 2) Measurable oxygen depletion in our planet due to the fact that the sum of the oxygen emitted in the combustion exhaust and that recycled by plants from the emitted CO₂ is smaller than the oxygen used in the combustion (negative oxygen balance);
 - 3) Measurable increase of carbon dioxide of dramatic proportions, with potentially catastrophic climactic changes;
- and other environmental problems, such as the production of poisonous NOx.

As a result of studies initiated in the early 1980's at Harvard University under DOE support (see review [1]), one of us (R.M.S.) has recently developed a new technology, called PlasmaArcFlowTM[1c] (Patented and International Patents Pending), for the production of environmentally acceptable combustible gases, called magnegasesTM(see the industrial web site [2a] and the scientific web site [2b]).

The new technology is primarily conceived to recycle nonradioactive liquid feedstock, such as antifreeze waste, engine oil waste, town sewage, as well as crude oil, etc., by flowing the liquid through a submerged electric arc between submerged electrodes within a metal vessel. The arc decomposes the liquid into its atomic constituents, ionizes the atoms, and forms a plasma in the immediate vicinity of the tip of the electrodes at about 10,000° F. The new technology then moves the plasma away from the arc, and controls its recombination into magnegases which bubble to the liquid surface where they are collected with various means, are pumped into conventional, low or high pressure, gas storage tanks, and then used for metal cutting, heating, cooking, automotive, and any other other fuel application [2].

It is evident that magnegases vary with the liquid used for their production. However, magnegases produced from different liquid of fossil fuel origin

have a similar composition, thus admitting a unified treatment. They also constitute magnegas with the highest energy content, thus constituting the most interesting class.

In fact, the plasma originating from the recycling of fossil waste is essentially composed of mostly ionized H, O, and C atoms (plus traces of other elements which generally precipitate as solids and, as such, are ignored hereon). Due to the known affinity of C and O, abundance of carbon in the plasmas assures the removal of oxygen via the formation of CO, thus preventing an explosive mixture of H and O. The PlasmaArcFlow then prevents the subsequent oxydation of CO, thus eliminating unwanted percentages of CO₂. The resulting gases are stable at ordinary temperature, do not self-ignite even at high temperature, and need a flame or a spark to ignite.

Therefore, magnegas of fossil waste origin are essentially constituted by H₂ and CO, with traces of O₂, H₂O, CO₂. The full combustion of such a mixture is manifestly without any possible carcinogenic or other toxic substance, thus resolving the environmental problem 1) of fossil fuels recalled above.

Since magnegas are fabricated, they can be produced in such a way that there still remains a significant percentage of oxygen in the exhaust. In this way, magnegas have a positive oxygen balance, and resolve the second environmental problem of fossil fuels.

Under a proper combustion studied in detail in this paper, carbon is mostly released in its solid form, resulting in small percentages of CO₂, thus resolving the third environmental problem of fossil fuel.

The exhaust of magnegas produced from fossil waste is constituted by: 50% to 60% H₂O (as water vapor); 10% O₂; 3% to 7% of CO₂; the remaining components being inert atmospheric gases.

Other features of the new technology important for this study are the following. Since magnegas are internally rich in oxygen, their combustion requires 30% to 40% of the air intake needed for fuels of fossil origin. This implies a large reduction of nitrogen participating in the combustion, with consequential reduction of toxic NO_x; for details on combustion exhaust one can inspect [2c].

All types of magnegas can be used in all existing internal combustion (IC) engines, via the sole change of external components, essentially dealing with the carburation, coil voltage, and timing [2].

The equipment for the production of magnegas, known under the name

of *Santilli's hadronic reactors* (Patented and Patents Pending), are commercially over-unity. In fact, independently certified measurements one can inspect at the USMG laboratory in Florida, have established that, for the reactor operating at atmospheric pressure, one unit of electric energy calibrated at the panel produces at least three units of energy in the gas, plus at least one unit of energy as heat in the liquid to be recycled, resulting in the over-unity of 4 (bigger over-unities are possible for the reactor operating at bigger pressures, due to the decrease of the gas bubbles, although they will be ignored in this paper).

As a consequence, hadronic reactors producing magnegas are essentially capable of tapping energy from liquid feedstock and from the carbon electrodes, in essentially the same way as Fermi's nuclear reactors tap energy from nuclei, with the difference that the former have been certified [2] to have no harmful radiations and leave no harmful waste, while the latter release harmful radiations and wastes.

Moreover, nuclear reactors are notoriously large and require large protections due to the harmful radiations, thus being solely usable in large plants far away from inhabited areas. By comparison, since they need no shield for radiations, hadronic reactors are small, typically having the dimensions of a desk [2a]. As a result, magnegas can be produced everywhere needed, thus avoiding the costs of transportation over large distance which are typical for fossil fuels.

Since magnegas are produced as byproducts of the recycling of liquid waste or crude oil, since their production equipment is commercially over-unity, and since they do not require transportation of fuels over large distances, the cost of magnegas is competitive over that of fossil fuels, of course, when produced in sufficiently large volume. In fact, the two incomes from the recycling of liquid waste and from the utilization of the heat, plus the high efficiency of the reactors imply very low operating costs.

The resolution of the alarming environmental problems caused by fossil fuels, their possible use in any existing engine, burner, or furnace, and their competitive cost over existing fuels, render magnegas serious alternative sources of clean fuels, thus deserving a serious study by the scientific community.

The reader should be also aware that, contrary to popular beliefs, large uses of hydrogen are potentially catastrophic for our planet, unless the hydrogen is produced via ecologically acceptable ways. Gasoline produces trillions

of cubic foot of CO₂ per day which is at least in part recycled by plants into O₂. By comparison, hydrogen has one tenth the energy content of gasoline, thus requiring at least ten times oxygen for the same performance (say, the same m.p.h.). Moreover, all atmospheric oxygen in the combustion of pure hydrogen is turned into water, thus being permanently removed from our planet due to the notoriously high cost of water separation.

A similar fate also holds for fuel cells, since they also operate by burning hydrogen or similar environmentally unacceptable fuel. Besides, fuel cells cannot be used in existing IC engines. Therefore, their uses leaves completely unchanged the current deterioration of our environment (since fuel cells are expected to be used only for *new* cars, thus leaving unchanged existing cars).

On similar grounds, electric cars can admittedly improve local urban environments, although they globally *increase*, rather than decrease, environmental problems, since electric power plants are known to be much more polluting than automobiles, whenever they are of fossil or nuclear type.

In conclusion, the new combustible fuels magnegas constitute a serious and real source of new clean fuels that are environmentally preferable, not only with respect to fuels of fossil origin, but also with respect to alternatives currently under study, such as hydrogen, fuel cells, and electric cars.

It should be mentioned that entropy increases in the transition from a solid state to a liquid or gas state. Therefore, the high efficiency of hadronic reactors does not violate conventional thermodynamics laws.

The study of this paper is hereon restricted, specifically, to the single magnegas produced from the recycling of antifreeze waste, since this is the gas subjected to the largest number of experimental measurements until now [1c]. However, our results are easily extendable to other types of magnegas. The reader should be aware that other types of magnegas, such as those produced from the recycling of oil waste or crude oil, have an energy content bigger than the magnegas produced from antifreeze waste.

2 The novel chemical structure of magnegas

All types of magnegas (again referred to combustible gases produced under an electric arc) possess a new chemical structure first identified by one of us [1b], which is characterized by clusters of ordinary molecules, radicals and atoms bonded together by attractive forces of primary magnetic origin (see

Ref. [1c], Chapter 8, for a comprehensive presentation).

As established by numerous Gas Chromatographic, Mass Spectrometric (GC-MS) tests under joint InfraRed Detectors (IRD), these clusters constitute a new chemical species different than that characterized by conventional molecules (i.e., clusters with a valence bond), since the magnegas clusters are stable at ordinary conditions which remain unidentified among known molecules while exhibiting no infrared signatures (other than those of conventional molecular constituents), thus confirming that the bond is not of valence type.

As well known in physics (although less emphasized in contemporary chemistry), whether conventional or novel, stable clusters detected by GC-MS equipment *cannot* exist without an *attractive* force. The specific and concrete identification of the attractive bond of electromagneclusters constitutes a central aspect in the study of magnegas, with implications similar to those of the valence for conventional molecules.

Extensive studies of this aspect have established that the primary attractive force responsible for the electromagneclusters is expected to be due to the magnetic polarization of the orbitals of valence and other electrons, from space to toroidal distributions. Conventional quantum electrodynamics establishes the existence of such a polarization whenever atoms and molecules are exposed to intense magnetic fields, as it is the case in the vicinity of the electric arc. Such a magnetic polarization creates magnetic North-South polarities along the symmetry axis of the toroid, which permit the stacking of atoms and molecules one after the other [1c].

The above analysis has permitted a quantitative interpretation of the detection via GC-MS/IRD of clusters possessing molecular weight all the way to 1,000 a.m.u. in a *light* gas, such as magnegas from antifreeze waste, whose highest molecular weight should be 44 a.m.u for CO₂.

Electric contributions are expected to exist but their study has not been conducted to date. Conventional molecules are mostly preserved in the new clusters (as established by the preservation of their IR signature). Therefore, valence electrons cannot contribute to the bonding force of the new clusters. Ionic contributions, even though unquestionably present, are notoriously unacceptable for a bond, because they carry the same charge, thus resulting in a *repulsive*, rather than attractive force. Electric polarization (essentially due to a deformation of the charge distribution of atoms) are also unquestionably present, although they are notoriously unstable and weak, while their

geometry does not lend to large clustering when acting alone.

As a result of the expected dominance of magnetic over electric contributions, the new chemical species composing magnegas is called "magnecules" or "magneclusters" [1b]. The same terminology will be adopted in this paper hereon.

When originating from fossil or organic waste, numerous GC-MS/IRD scans [1c] have established that gas magnecules are essentially constituted by conventional molecules H_2 , CO , CO_2 , H_2O , plus individual atoms of H , O , and C , as well as radicals such as HO .

It is evident that the bonding of atoms and molecules into new clusters constitutes new means for storing energy in a combustible gas, in addition to the conventional valence means in ordinary fuels. Therefore, magnecules have a primary relevance for the study of the combustion of magnegas. It is also evident that a deeper understanding of the magnetic origin of the new clusters in magnegas will permit an increase of their energy content, since the size and strength of magnecules is directly proportional to the magnetic field used for its formation.

Magnegases have additional new means for storing energy deep into the structure of conventional molecules. Recall that any peak in the IR signature of conventional molecules denotes a corresponding valence bond. For instance, an IR signature with two peaks for CO denotes the existence of a valence bond of the type $C=O$.

Numerous independent measurements on magnegas [1c, 2a] have established that the IR of conventional molecules is "mutated" with the presence of new additional peaks. Since all valence electrons are generally used in the molecules, the new IR peaks can only be explained via the creation of new internal bonds of non-valence type. Again, the magnetic origin of these new bonds has resulted to be plausible, and essentially consists in the toroidal polarization of the orbitals of internal electrons under external, strong magnetic fields. For the case of $C=O$, these internal toroidal polarizations imply the creation of the pair of magnetic polarities $(North-South) \times (North-South)$. The creation of internal magnetic bonds then alters the entire thermochemical horizon, beginning with *new* values of binding energies for *conventional* molecules.

It is evident that a deeper understanding of the new internal bonds in conventional molecules may permit a corresponding increase of energy storage in fuels, since, again, their number and strength depends on the intensity of

the external magnetic field used for their creation.

A technical understanding of this paper also requires a knowledge of various additional anomalous features of magnegas, such as their *anomalous adhesion* (which occludes feeding lines with small sectional areas usually acceptable for conventional gases, thus preventing the passage of large magnecules to be detected); *mutations* (generally referred to macroscopic alterations in time of magnecules under the same conditions following break-down due to collisions and subsequent recombinations); *alteration of physical characteristics* (such as macroscopic changes in average molecular sizes, density, viscosity, etc.); and other anomalies.

In this paper we study the above anomalous new means for storing energy in magnegas and introduce, apparently for the first time, an estimate of the binding energy of magnecules.

3 The novel combustion of magnegas

Predictably, the new chemical structure of magnegas implies that its combustion is fundamentally different than the combustion of conventional fuels, possessing a conventional chemical structure. A conventional fuel is constituted by a given conventional molecule, and generally burns according to thermochemical reactions. In this sense, the combustion of a conventional fuel can be referred to the firing of a "single stage rocket".

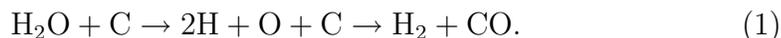
Magnegas are instead constituted by conventional molecules bonded into the new magneclusters, thus having a multi-stage chemical structure. In addition, as we shall see, magnegas generally have a sequence of dominant thermochemical reactions. In this sense, the combustion of magnegas is here referred to the firing of a "multi-stage rocket", with different fuels in different stages.

In this paper we study, apparently for the first time, the primary chemical reactions in the combustion of magnegas of fossil origin. Our main conclusion is that fuels synthesized under intense electric and magnetic fields can indeed release energy in amounts much bigger than those predicted by conventional chemical reactions.

To initiate this study, consider the simplest possible magnegas, that produced from ordinary tap water and a carbon electrode via an electric arc having 1,000 A, 40 V DC, and the PlasmaArcFlow set to produce a gas with

about 45% H₂ and 45% CO, the remaining percentages being composed of H₂O, CO₂, and O₂. The primary effect of the arc is the dissociation, H₂O → 2H + O. Owing to the excess of carbon in the plasma we then have the known reaction, 2H + O + C → H₂ + CO, which explains in part the reason why H₂ and CO are observed in essentially equal percentages.

Consider then the elementary sequence of reactions



Let us calculate the energy balance for the reaction channel. Irrespective of possible intermediate reactions, the minimal energy needed will be the same, and it can be calculated via to the energy balance:

$$E[\textit{producing}] = E[\text{H}_2] + E[\text{CO}] - E[\text{H}_2\text{O}] - E[\text{C}], \quad (2)$$

where $E[\text{H}_2]$, $E[\text{CO}]$, $E[\text{H}_2\text{O}]$, and $E[\text{C}]$ denote ground state energies.

Since the main channel is (1) one can suppose that, microscopically, the production of H₂ and CO occurs as follows. Immediately after a given H₂O molecule has been bombarded by the electrons of the arc, it dissociates. Then, near to the arc (in a lower temperature region, to which the atoms are moved by flow), when the C atom occurs near the H+O+H complex, the O atom captures the C atom while the two H atoms composes the H₂ molecule.

Processes of ionization of H, O, C, H₂O, OH, and CO, under the effect of the arc, as well as excited states and radiation, are not considered here, for simplicity.

The process of creation of H₂ and CO are thus running in parallel, with several similar processes occurring in neighborhood of a given H₂O molecule. So, these elementary processes occur at the same conditions (temperature, pressure, external electromagnetic field produced by the arc and neighbor electrons, ions and atoms).

This is the point where and when the production of magnecules in a gaseous phase takes place in part. The magnecules may, therefore, consist of several H₂ and/or CO molecules, plus individual H, O and C atoms and OH radicals, as well as C-C and C-H dimers, bonded to each other by chains of North-South polarities created by the toroidal polarization of the orbits of valence and other electrons [1b].

As the PlasmaArcFlow moves the magnecules away from the high temperature region, magnegas cools down, and bubbles to the surface of the liquid, where it is collected, for storage and use.

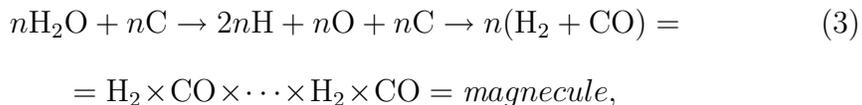
Due to the detected rather big mass of magnecules (up to 1000 a.m.u.) at ordinary temperature, it seems that CO (with mass 28 a.m.u) is the heaviest molecular constituents in large percentage, followed by the heavier CO₂ molecule (with mass 44 a.m.u.), although in much smaller percentage.

Indeed, it is hard to imagine that, the peak with 416 a.m.u detected in magnegas by GC-MS/IRD tests can be due to a magnecule consisting of 208 H₂ molecules. Such a cluster can probably not survive at room temperature due to its huge size, as well as linear character of its bond. In fact, a magnecule of 208 bond lengths of H₂ has the linear length $208 \times 1.4 \approx 300$ bohrs, thus being excessively long for stability.

The same weight of 416 a.m.u. can be better represented by only 15 CO molecules, in which case the linear size is $15 \times 2 = 30$ bohrs. In addition, CO has plenty of electrons (some of which are unpaired), in contrast to H₂. These electrons might be responsible for magnetic polarizations as needed in the magnecule, in accord to the observed infrared spectrum of CO [1c].

However, the magnecules consisting solely of CO molecules can not probably explain why magnegas possesses an anomalously high energy release since H₂ is a combustible component too, which can make a great contribution to the total energy released. Thus, most likely, the magnecules of 416 a.m.u. consists of both CO and H₂, e.g., with 14 CO and 12 H₂ molecules. The latter assumption explains the magnecule mutation of two a.m.u.

In summary, the elementary reaction channel (1) for producing H₂ and CO, can be extended to



where the final system is a type of magnecule consisting of equal number n of bonded H₂ and CO molecules (not n separate molecules H₂ and n separate molecules CO), where "×" denotes the magnetic bond.

The further assumption of 14 CO, 11 H₂ and 2 isolated H atoms then explains the magnecule mutation of only one a.m.u. This latter assumption is not considered in these introductory remarks for simplicity.

The following remark is in order. We should note that the magnetic origin of the bond is not critical here, so "×" can be thought of as some kind of bond which is weaker than the bonds H-H and C=O. So, the model, which we use here, is in essence rather general, and can be used for other

possible interpretation of the attractive force permitting the existence of the anomalous clusters.

Under the above assumptions, the energy needed for production of magne-
cules is

$$E[\textit{production}] = E[\textit{magnecule}] - nE[\text{H}_2\text{O}] - nE[\text{C}], \quad (4)$$

where $E[\textit{magnecule}]$, $E[\text{H}_2\text{O}]$, and $E[\text{C}]$ are ground state energies, and we assume, again for simplicity, the magnecule as consisting of equal number n of CO and H₂ molecules.

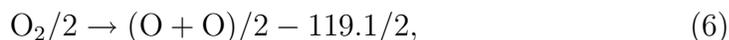
The above amount of energy may be indeed different from (2) because the ground state energy of the magnecule, $E[\textit{magnecule}]$, is evidently not equal to $nE[\text{H}_2] + nE[\text{CO}]$ due to the binding energy of magnecule, eventual deformation of orbitals, and other internal electronic effects. This is the first case where the anomalous efficiency of the PlasmaArcFlow reactor may originate.

4 Combustion of H₂ and CO in equal percentage

In this section we present elementary calculations of reaction heats, for the combustion of H₂, CO in a 50%+50% mixture. The binding energies of interest are presented in Table 1 [4], where the complete dissociation of gas states of reagents to gas states of product atoms is assumed at temperature $T = 25$ C.

Combustion of H₂: $\text{H}_2 + \text{O}_2/2 \rightarrow \text{H}_2\text{O}$.

The reactions are:



So, the energy balance is $2 \times 110.6 - 119.1/2 - 104.2 = 57.5$. Thus,

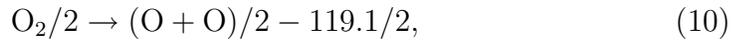


Combustion of CO: $\text{CO} + \text{O}_2/2 \rightarrow \text{CO}_2$.

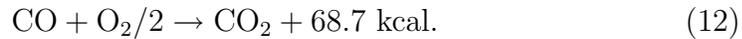
Diatomic molecules		Diatomic molecules	
H–H	104.2	C=O	255.8
O=O	119.1	N≡N	192.0
Manyatomic molecules		Manyatomic molecules	
C–O	85.5	O–H	110.6
C=O in CO ₂	192.0	O–O	35
C=O in formaldehyde	166	C–H	98.7
C=O in aldehydes	176	C–C	82.6
C=O in ketons	179	C=C	145.8
C=N	147	C≡C	199.6

Table 1: Binding energies, kcal/mole. $T = 25\text{C}$.

The reactions are:



So, the balance is $2 \times 192 - 119.1/2 - 255.8 = 68.7$. Thus,



Combustion of the 50%+50% mixture of H₂ and CO.

The balance is $2 \times 110.6 + 2 \times 192 - 119.1 - 255.8 - 104.2 = 126.1$ kcal per 2 moles (1 mole of H₂ and 1 mole of CO). For 1 mole of the mixture, we then have $126.1/2 = 63$ kcal. Thus,



So, the mixture of H₂ and CO gives bigger reaction heat than 100% H₂ gas.

Note that, since 57.5 kcal/mole is equal to 300 BTU/cf, the 50%+50% mixture of H₂ and CO gives about 63 kcal/mole = 330 BTU/cf.

5 Combustion of acetylen

In this section we study the thermochemical properties of acetylene because useful for the study of magnegas when used for metal cutting [2a].

Pure acetylene (which *is not* the acetylene used in the metal cutting industry) is a liquid with the linear molecule $C_2H_2 = H-C\equiv C-H$, boiling temperature of $T = -84C$, and melting temperature of $T = -81C$. The heat released in the combustion of acetylene is 311 kcal/mole, at temperature $T = 25C$.

The combustion of acetylene in pure oxygen occurs via the reaction



holding at the flame temperature of about $T = 2800C$.

It is interesting to note that, e.g., ethane, C_2H_6 , has a bigger reaction heat of 373 kcal/mole, but it holds at the smaller flame temperature $T \ll 2800 C$ due to the reaction,



producing three times water of the preceding reaction. A bigger part of the total released energy is spent in water evaporation, by decreasing the flame temperature. It follows that ethane is a combustible gas less efficient than acetylene for metal cutting.

Magnegas is currently in regular production and sales for metal cutting [2a]. Its daily uses in this field has established that magnegas is more effective than acetylene in metal cutting, because: 1) the pre-heating time is about half; 2) the cutting speed is almost double; and 3) the combustion exhausts are dramatically cleaner than those of commercially sold acetylene; 4) there is no "back-flash" (reflection of flame in rusty surfaces); and 5) the cut is manifestly cleaner. Magnegas is also much safer because stable, as compared to the notoriously unstable commercial acetylene; it can be produced anywhere needed with a desk-size equipment, thus avoiding transportation altogether; and it is cheaper than acetylene.

The better efficiency of magnegas compared to acetylene is primarily due to the combination of a bigger flame temperature and energy density, which reduce the pre-heat time and increase the cutting speed.

In fact, the flame temperature for pure H₂ is about $T = 3100$ C, so that 50% of H₂ and 50% of CO in magnegas could provide a flame temperature bigger than that of acetylene.

An additional reason for the bigger efficiency of magnegas in metal cutting is due to the fact that only a portion of oxygen is of atmospheric origin, while the remaining portion originates from: 1) free O-atoms in magnecules; 2) the presence in magnecules of HO-dimers; and 3) a possible dissociation of C≡O, C=O, and C–O groups, which we expect to be present in magnegas. These features are confirmed by the dramatic decrease of air or oxygen for the burning of magnegas as compared to acetylene, as well as by observed carbon residues.

It should be noted that the value of the reaction heat of 311 kcal/mole, has been measured for the water in liquid state (see Eq. (14)), while the combustion heat of magnegas has been studied until now only for water produced at the vapor state. Therefore, the comparison of combustion heat of magnegas with that of acetylene should require both combustion heat measured under the same conditions, i.e., both combustions being measured for water produced either at the liquid or at the gas state, since the evaporation heat of water is considerable (10.4 kcal/mole at $T = 25$ C). This occurrence is an additional reason for the difficulties encountered until now in achieving a scientific measurement of the energy content of magnegas [2a].

Additional difficulties in measuring the energy content of magnegas are due to difficulties in achieving its complete combustion in air. This is due to the anomalous means of storing energy, some of which is stored deep into the structure of conventional molecules, which evidently requires special conditions for complete combustion.

The Konovalov's equation permits an estimate of the combustion heat,

$$\Delta H = -(47.02m + 10.5n + x) \text{ kcal/mol}, \quad (16)$$

where m is number of O atoms used for complete combustion, n is number of moles of the water produced, and x is the correction coefficient, which is a characteristic constant for each gas. Therefore, final measurements on the magnegas combustion will permit the identification of its characteristic constant x .

6 Combustion of magnegas

It is evident that the combustion of magnegas requires the oxidation, first, of magnecules, and then that of conventional molecules H_2 and CO . Therefore, the preceding energy calculations for a gas with 50% H_2 and 50% CO do not apply for a magnegas with the same conventional chemical composition. Additional novelties occur for other types of magnegases, such as that produced from the recycling of antifreeze waste, whose energy content has been conservatively estimated to be of the order of 900 BTU/cf [2a].then, the bonding structure of magnecules plays a key role in understanding the energy content of magnegas.

To begin, the known reactions $H_2 + O_2/2 \rightarrow H_2O$ and $CO + O_2/2 \rightarrow CO_2$, should be replaced by the reaction



which may give increased energy released per each H_2 molecule. Here, n , m , k , l , ... are numbers, and the original magnecule is assumed to consist of both H_2 and CO molecules.

The energy balance for the combustion of magnecule is then given by:

$$E[\text{combustion}] = mE[H_2O] + kE[O_2] + lE[CO_2] + \dots - E[\text{magnecule}], \quad (18)$$

where $E[H_2O]$, $E[O_2]$, $E[CO_2]$, ... are ground state energies of the molecular constituents, and $E[\text{magnecule}]$ is ground state energy of the the original magnecule.

A way to calculate this energy balance is to use dissociation energy of the magnecule, $D[\text{magnecule}]$. However, we should note that $D[\text{magnecule}]$ is different for magnecules of different mass and composition.

For chemical reactions, one should take into account the value of the reaction constant K . For example, for the reaction $H_2 + O_2/2 \rightarrow H_2O$ ($\Delta H = -57.5$ kcal), the reaction constant is very big, $K = 10^{40}$ at $T = 25$ C, thus indicating an almost total combustion of H_2 gas at $T = 25$ C.

The general rule is that, for all *highly exothermic* reactions (typically, with $\Delta H < -15$ kcal/mol), the reaction constant is of high value. The opposite direction of the reaction, $H_2 + O_2/2 \leftarrow H_2O$, is realized only at very high temperatures, at which $K < 1$. The value $K = 1$ means equilibrium of a reaction, while $K < 1$ means that a reaction runs in opposite direction.

In general, the relation between the reaction heat, ΔH , and the reaction constant, K , is as follows:

$$-2.303RT \log K = \Delta G, \quad (19)$$

where

$$\Delta G \equiv \Delta H - T\Delta S, \quad (20)$$

$R = 1.986 \text{ cal}\cdot\text{K}^{-1}\cdot\text{mol}^{-1}$, T is temperature in Kelvins, and ΔS is the entropy of the reaction. The latter is numerically big if the initial reagents have molecular structures more ordered than the end products, i.e. there is an *increase* of entropy S during the reaction.

The above outline on the reaction constant and reaction entropy helps us to conclude that the combustion of magnegas is characterized by a very high value of the reaction constant (perhaps even bigger than $K = 10^{40}$ at $T = 25\text{C}$). In fact, the combustion of magnegas is a highly exothermic reaction, and the magnecules have a structure much more ordered than the product of the combustion. Therefore, during the combustion of magnegas we have a large increase of the entropy $\Delta S > 0$. These two factors lead to very high value of the reaction constant K for the combustion of magnegas.

The table values of ΔH and ΔG are given at normal conditions ($T = 25\text{C}$, $p = 1 \text{ atm}$). However, ΔG is a function of the temperature. For most elements, ΔG of oxidation reactions (linearly) increases with the increase of the temperature. Thus, the resulting oxides are less stable at high temperatures than at low temperatures (typical example is H_2O which dissociates at very high temperatures).

It is interesting to note that the oxidation of carbon to carbon monoxide, e.g., $\text{C} + \text{CO}_2 \rightarrow 2\text{CO}$, is almost the only oxidation reaction for which ΔG *decreases* with the increase of the temperature. Here, the number of moles increases about twice during the reaction. As a result, the entropy greatly increases, $\Delta S > 0$. Therefore, the CO molecule is *more* stable at high temperatures than at low temperatures (for example, it is about twice more stable at 3000C than at 1000C).

Another ecologically very important aspect in the combustion of magnegas is therefore the *reduction of CO_2 via the oxidation of carbon atoms present in magnecules, and its subsequent dissociation as in Eq. (9) to release the oxygen needed for the burning of H.*

Since the stability of CO increases with the temperature, *a better quality of the exhaust is reached at lower original temperatures of magnegas*. This result should be compared with the opposite occurrence for natural gas and for other fuels, which are generally *pre-heated* prior to combustion.

Another important characteristics of a reaction is the reaction rate. Various tests [2a] have show that the combustion of magnecules is faster than the combustion of their molecular constituents. Santilli-Shillady isochemical models of molecular structures permits the following understanding of this additional anomaly.

In their natural conventional, and non-polarized states, H₂ and O₂ molecules have the usual (spherical) shape due to rotations. However, an inspection of the isochemical model of the water shows that such configurations are not suited for the reaction of H and O into H₂O. In particular, the orbitals of H₂ require a toroidal configuration as a condition for their bonding to the oxygen, a similar occurrence holding for the oxygen too.

It then follows that *magnetically polarized molecules of hydrogen and oxygen have a bigger reaction rate than the same molecules in un-polarized conditions, since they have a distribution of the valence electrons more suitable for the reaction itself*. Evidently, a bigger reaction rate implies a bigger power.

Moreover, the combustion of a magnecule consisting of H₂ and CO, does not require the necessary previous dissociation of the O₂ molecule (O₂ → 2O – 119.1 kcal), because each O-atom in a magnetically polarized O₂ molecule is ready for the combustion. Therefore, the magnecular structure acts as a kind of catalysis, in which both O-atoms of the O₂ molecule start to react with the nearest pair H₂ × H₂, or H₂ × CO, or CO × CO almost simultaneously; see Fig. 1.

This occurrence also implies that less amounts of external energy is needed to activate the reaction, resulting, again, in an anomalous energy release in combustion. Usually, the activation energy is supplied by heat. Therefore, we can conclude by saying that the combustion of magnegas can be initiated at smaller temperature, in comparison to that of the simple mixture of H₂ and CO gases. The reduction of pre-heating time of about one-half by magnegas as compared to that for acetylene, is in agreement with the above interpretation.

Due to the presence of magnecules viewed as heavy complexes of H₂ and CO, one cubic foot of magnegas contains in fact *bigger number* of H₂ and

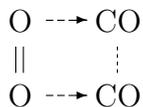


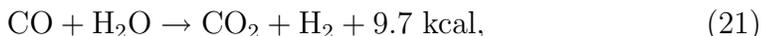
Figure 1: Collision of O₂ and a pair of correlated CO molecules.

CO molecules than it is for the respective simple mixture (i.e., without the clusters) of these two gases, at the same temperature and pressure. Clearly, magnegas is far from being an ideal gas. For example, for ideal gases the number of molecules is $N_A = 6.02 \cdot 10^{23}$ per 22.414 liters of volume, at normal conditions ($T = 0$ C, $p = 1$ atm). This is not the case for real gases (e.g. CO₂), and especially for the gases containing macroscopic percentage of particles of huge mass, 400...800 a.m.u., (and therefore big effective size) which are interacting with each other. Thus, the bigger number of H₂ and CO molecules per cubic foot of magnegas can be considered as one of the simple reasons of high energy content of magnegas which has been measured and calculated per cubic foot.

The above note implies that more experimental study of the thermodynamics of magnegas, viewed as a real gas, is needed. For example, measurement of the critical parameters —pressure p_k , volume V_k , and temperature T_k — and the Jole-Tomson effect is of primary interest here. Also, we need in measurement of the energy released of magnegas combustion not per cubic foot but per mole, to obtain a value of the reaction heat, which we then can compare to the standard values of the reaction heats, given in kcal/mol, at $T = 25$ C and normal pressure.

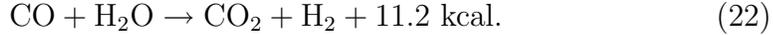
Note that oxidation of C can result in various compounds, CO, CO₂, C₃O₂, C₅O₂, and even C₁₂O₉. The reaction constant K varies with the reaction temperature so that at $T = 600...700$ K the product is almost only CO₂ while at about $T = 1300$ K the product is almost only CO. At low temperatures, the resulting carbon monoxide does not oxidize further to carbon dioxide CO₂ despite the fact that this is thermodynamically much preferable since the activation energy of the reaction $\text{CO} + \text{O}_2/2 \rightarrow \text{CO}_2$ is high. Also, a lack of air (oxygen) supports producing of CO.

Below, we consider the reaction,



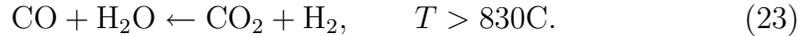
(low exothermic, experimental value is $\Delta H = -9.7$ kcal/mol, $K = 10^5$, at

$T = 25$ C, gaseous states, constant pressure), which also can take place. The theoretical value of the reaction heat is due to $\text{CO} \rightarrow \text{C} + \text{O} - 255.8$, $\text{H}_2\text{O} \rightarrow \text{O} + 2\text{H} - 2 \times 110.6$, $\text{C} + 2\text{O} \rightarrow \text{CO}_2 + 2 \times 192$, and $\text{H} + \text{H} \rightarrow \text{H}_2 + 104.2$. So, the balance is $104.2 + 2 \times 192 - 2 \times 110.6 - 255.8 = 11.2$. Thus,



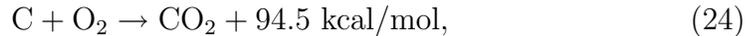
The obtained theoretical value, 11.2 kcal, is a bit bigger than the above experimental value, 9.7 kcal, but it is acceptable within the provided accuracy.

The reaction constant of this reaction decreases with the increase of temperature and is about $K = 1$ at temperature $T = 830$ C so that at higher temperatures the reaction goes in opposite direction,



At lower temperatures, $T = 700 \dots 830$ C, we should expect that magnegas exothermically reacts with water due to (21), thus decreasing percentage of CO and increasing percentage of CO_2 and H_2 in magnegas. At room temperatures, CO does not react with water because of the lack of activation energy needed to initiate the reaction.

Using the reactions



we obtain the endothermic reaction,



which runs from left to right at high temperatures and/or high pressures, and it runs from right to left at low temperatures. This reaction is important in *optimization of the PlasmaArcFlow reactor to produce magnegas with low percentage of CO_2 , and also to cool down the liquid*. Also, competition of the reactions (25) and (26) is important in *optimizing the magnegas combustion*. More studies are needed to identify optimal range of temperatures and pressures, for the reactions (12), (21), (24)-(26), to get desired content of magnegas, content of the exhaust, and its energy characteristics.

It is worthwhile to note that the mixture of CO and H_2 , used as a gas fuel and in a synthesis of hydrocarbons, can be produced by the reaction of water

vapor flow with overheated carbon (coal). The PlasmaArcFlow reactor can be considered as an alternative method to produce such a mixture, which is used in very important process of *the catalytic synthesis of various hydrocarbons*.

Also, it is known that the mixture of 25% (volume) of CO, 70% of N₂ (nitrogen), and 4% of CO₂ is used as a gas fuel, with the energy released about 1000 kcal per cubic meter.

7 Structure of magnecules

In this section, we discuss on possible structures of magnecules and the origin of the bonds in magnecule.

Currently, not much is known on the physical-chemical characteristics of magnegas besides the basic chemical content, energy released, infrared spectroscopy and gas-chromatography mass-spectroscopy data, and some laboratory and industrial tests certifying its anomalous energy characteristics and combustion properties [1, 2, 3]. Particularly, the IR/GC-MS data of magnegas at room temperatures, $T = 10...20\text{C}$, show that the (fragments of) magnecules have masses up to 1000 a.m.u., (typically, 400...800 a.m.u. for the biggest mass in macroscopic percentage), and by the mass-spectra they are not recognized as known molecules by computer search among more than 100,000 known species. Also, the infrared spectra reveal sharp peaks identified as CO and CO₂ spectra, and a big number of very small peaks, for the IR/GC-MS scanned masses 40...1000 a.m.u. Here, the presence of CO infrared peaks is of somewhat strange character since $M[\text{CO}] = 28$ a.m.u. is out of the scanned mass range, $M > 40$ a.m.u., so that none of separate CO molecules have been analyzed by the infrared spectrometer. This can be interpreted as that CO molecules are inside the magnecules, or some other effects simulating appearance of the CO peaks take place.

The presence of CO₂ infrared peak, $M[\text{CO}_2] = 44$ a.m.u., is not unexpected and can be interpreted as that there are some percentage of CO₂ in magnegas (as it is indeed the case due to chemical analysis), and/or CO₂ molecules are also inside the magnecules. The small infrared peaks have not been recognized by computer search as the peaks corresponding to known molecules. They could be interpreted as the vibrational-rotational spectrum of the magnecules. We refer the reader to Refs.[1, 2] for the other interesting information on magnegas, and its applications.

Conduction of precise tests on the basic characteristics of magnegas and the detected magnecules is much important. Typically, they are:

(Averaged) Molecular mass;

Density;

Boiling temperature;

Melting temperature;

Critical temperature at which the detected magnecules of magnegas are completely destroyed (temperature stability of the combustion properties);

Oxidation states;

Electronegativity;

Electrical conductivity;

Thermal conductivity;

Heat of vaporization;

Specific heat capacity;

First ionization potential;

Crystal structure;

Acid/Base properties;

Molecular volume;

Nuclear magnetic resonance (NMR) spectrum;

Raman spectrum;

Magnetic susceptibility;

Dissociation energy of magnecules;

Electric charge of magnecules;

Magnetic moment of magnecules;

Roentgen-structural analysis of magnecules.

The NMR spectrum of magnegas is one of the best ways to see experimentally that there is a kind of magnetic bonds in magnecules if H atoms are present in magnecules. NMR test will give us information on the strength of magnetic field inside the H-atoms, to an extremely high accuracy. So, if H₂ molecule is polarized in magnecule, even to a very small degree, then NMR spectrum would show this clearly due to high sensitivity provided by modern NMR facilities. Also, this would give some experimental grounds, at a microscopic level, to develop a realistic model for magnecules.

The NMR chemical shift, δ , is an entity characterizing intensity of magnetic field experienced by the nucleus of H-atom (proton). It is measured in ppm, in respect to the shift of tetramethylsilane (TMS), (CH₃)₄Si, which

is taken as the standard zero chemical shift, $\delta[\text{TMS}] = 0$ ppm. For example, $\delta[\text{bare proton}] = 31$ ppm, $\delta[\text{H-atom}] = 13$ ppm, $\delta[\text{H}_2 \text{ gas}] = 4.4$ ppm, $\delta[\text{H}_2\text{O at T=0 C}] = 5.4$ ppm, $\delta[\text{H}_2\text{O vapor}] = 0.7$ ppm. $\delta[\text{HBr}] = -4.2$ ppm. The above differences in values of δ are due to different degrees of diamagnetic screening of the proton caused by electrons; less value of δ means that bigger diamagnetic screening takes place.

For the case if H_2 is not in magneclules of magneclgas, we would see the NMR peak at about $\delta[\text{H}_2 \text{ gas}] = 4.4$ ppm. For the case if H_2 is in magneclules of magneclgas, we would see the NMR peak at some other value of δ . In addition, we would see the *number* of H-atoms in magneclule, and, if these H-atoms are characterized by different electronic (magnetic) environment inside the magneclule, we would see several peaks each of which is splitted due to eventual spin-spin interaction of the H nuclei provided by the molecular (magneclular) bonds.

The possible types of bonds and mechanisms of creation and stability of the magneclules are:

1. Valence bonds (for substructures);
2. Hydrogen bonds (for substructures);
3. Polymerization (for substructures);
4. Magnetic bonds due to polarized electronic orbits;
5. Electric polarization;
6. Van der Waals bonds;
7. Three-center bonds;
8. Two-dimensional quantum tunnel effect;
9. Delocalized electrons; etc.

Below, we consider, in a more detail, some of the possible types of bonds in magneclule.

1. Valence bonds?

In Fig. 2, we present chemical structure of a compound which simulates presence of six CO molecules and five H_2 molecules. This compound can be thought of as one of the candidates to magneclules if we adopt the hypothesis that magneclule is due to *valence* bonds between H, C, and O elements.

Indeed, here all the valence bonds of the H, C, and O have been used thus giving support to a stability of the compound, and, this structure can be extended by inserting additional vertical H-O-C-C-O-H lines thus providing bigger mass of the resulting compound, up to the 1000 a.m.u. Moreover, H-H (104.2 kcal/mol) and C=O (255.8 kcal/mol) binding energies are bigger or comparable to the binding energies of the valence bonds presented in Fig. 2 (see Table 1), with the weakest bond being C-C (82.6 kcal/mol), thus partially explaining why such a compound, when it is destroyed, could give the detected H₂ and CO molecules of magnegas.

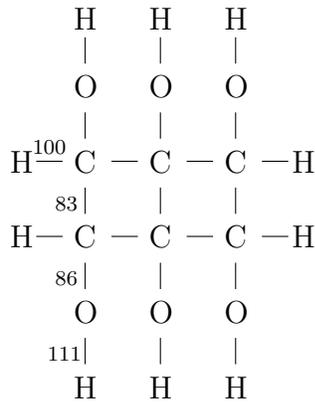


Figure 2: Compound simulating by its content six CO and five H₂. The numbers near bonds indicate corresponding average binding energies, kcal/mol.

However, such a compound appears to be not relevant as a model of real magnecules. Usually, at temperatures $T < 100\text{C}$, heat excitations of molecules are not capable to destroy the bonds with the binding energies bigger than 30...35 kcal/mol.

At room temperature, magnegas is stable, so we can conclude that the binding energy of the specific bonds in magnecule is estimated to be

$$B[\text{magnecule}] > 25...30 \text{ kcal.} \quad (27)$$

Due to the observed difference of the GC-MS spectra for the same magnegas at different time of measurement [1], we conclude that the magnecules are metastable at $T = 300\text{K}$ so that the specific bonds in magnecule are partially

destroyed by heat excitations at $T = 300\text{K}$. Therefore, in (27) we should make correction to lower permitted values by taking, conservatively,

$$B[\text{magnecule}] > 20\dots 25 \text{ kcal.} \quad (28)$$

The distribution of peaks in the GC-MS spectra of magnegas tells us that the charged fragments of magnecules are distributed densely, with no evident order, and almost linearly increased mass, up to some highest value of mass (e.g., 416 a.m.u.), which can be interpreted as a mass of single-ionized magnecule. So, it seems that that all the *specific bonds in magnecule are characterized by approximately the same value of the binding energy*. Therefore, the magnecule does not have something like a hard core which could be detected at a soft electron beam in mass-spectrometer.

The infrared spectrum of magnegas [1, 3] does reveal presence of the valence bonds C-H (high intensity IR), O-H (sharp IR), C-C (weak intensity IR), and/or C-O (high intensity IR), as well as C=O and O=C=O. However, GC-MS/IR analysis, based on about 138,000 compound data library, does not show presence of ordinary compounds except for the associated IR peaks of carbon monoxide and carbon dioxide. In addition, big number of strong bonds (like valence bonds) in magnecule would require much energy to be destroyed while, e.g., the measured anomalously high value of the energy released at magnegas combustion leads us to supposition that the specific bonds in magnecule are not strong. Thus, in general we can rule out the hypothesis that the specific bonds in magnecule are due to standard valence bonds.

It is worthwhile to note that, e.g., cobalt hydrocarbonyl, $\text{HCo}(\text{CO})_4$, containing both H and CO, is a gas, at room temperatures. Such type of a compound is known as somewhat unusual because neutral metal is bonded to carbon monoxide CO, which mostly conserves its own properties. In a strict sense, this type of bond is not a standard valence bond. Another example is magnesium carbonyl, $(\text{CO})_5\text{-Mn-Mn}-(\text{CO})_5$ (melting point is 66 C), where the bond Mn-Mn is of about 40 kcal strength.

Also, it is interesting to note that nickel carbonyl, $\text{Ni}(\text{CO})_4$, formed at $T = 80\text{C}$, is a gas at room temperatures, and dissociates, $\text{Ni}(\text{CO})_4 \rightarrow \text{Ni} + 4\text{CO}$, at $T = 200\text{C}$. Thus, the binding energy of the bond between *Ni* and CO is of about 30 kcal. We could expect that the magnecules have a kind of hydrocarbonyl structure like $\text{C}(\text{CO})_n$.

It is remarkable to note that one can try to destroy magnecules by ultra-violet light, which supplies energy of about 70 kcal/mol for each absorbed mole of photons. However, this is the case only if magnegas effectively absorbs the UV light.

2. *Hydrogen bonds?*

Since magnegas contains hydrogen the specific bonds in magnecule could be due to the hydrogen bonds. This bond originates from H atom mediating two other atoms by sharing its electron with one atom and its proton shifted to the other one. The binding energy of the hydrogen bond is about $B_H = 5$ kcal/mol. Examples are HF (liquid), with the chain $\cdots\text{H}\cdots\text{F}\cdots\text{H}\cdots\text{F}\cdots$, and H_2O (liquid), where the hydrogen bonds are responsible for peculiar properties of water. We see that the hydrogen bonds are also too weak, to meet the above estimated value (27) of the binding energy of the specific bonds in magnecule. However, we should note that in the case of several hydrogen bonds in parallel between two molecules the overall binding energy is evidently increased.

Even if we assume that the specific bonds in magnecule are a kind of "composite" bonds, Van der Waals bonds plus hydrogen bonds, the estimated upper total value, $B_{VdW} + B_H = 10$ kcal/mol, still does not fit $B[\text{magnecule}] > 20\dots25$ kcal. It follows from the energy estimation (27) that the specific bond in magnecule are weaker than typical valence bonds and stronger than typical Van der Waals and/or hydrogen bonds, for a structure consisting of H, C, and O atoms.

3. *Polymerization?*

It is quite interesting to note that there is the reaction producing an explosive compound, potassium carbonyl, $6\text{CO} + 6\text{K} \rightarrow \text{K}_6(\text{CO})_6$, which is used to obtain unusual carbon monoxide (carbon monoxide complex), $(\text{CO})_6$.

This structure is believed to exist due to polymerization. For example, a typical polymerization (e.g., of propylene, $\text{CH}(\text{CH}_3)\text{CH}_2$) is owing to C-C bond, which is characterized by the binding energy about 72...83 kcal/mol, with the reaction heat of about $\Delta H = -20$ kcal/mol per each molecule of the linear chain of polypropylene. We see that the typical value of the binding energy is much bigger than 30...35 kcal/mol. However, some mechanisms of interaction between CO molecules can also make a contribution here because of the specific electronic structure of CO molecule. So, we could expect lower

values of the binding energy between two neighbor CO molecules in $(\text{CO})_6$ complex. It is a consequence of the existence of $(\text{CO})_6$ that there may exist higher mass carbon monoxide complexes, $(\text{CO})_n$, with $n > 6$.

In any case, the known type of carbon monoxide complex, $(\text{CO})_6$, is a **direct confirmation that the above conjectured CO \times CO bond really exists, as it is known in practical chemistry.** So the existing complex



where " \times " denote a bond, is the best known real candidate to be a kind of magnecule. We should calculate whether the binding energy of this bond satisfies the condition (27).

The complex of type (29) would give mass-spectrum which exhibits periodicity in molecular masses of its fragments. Indeed, the weakest bonds in (29) are evident so that the complex (29), under the influence of the electronic beam in mass-spectrometer, would dissociate by separating integer number of (ionized) CO molecules. However, the mass-spectra of magnegas does not reveal periodicity with mass 28 a.m.u. as the smallest step. Instead, we observe almost randomly distributed masses of the fragments, with the minimal mass difference being 1 a.m.u.

Thus, we are led to the assumption that there are some other types of magnecules in magnegas, in addition to (29). We expect presence of H atoms in magnecules which could provide (multiple) hydrogen bonds. The -O-O- group serving, for example, as a peroxide bridge, could be present here as well.

4. *Magnetic bonds?*

To start with, study of the effect of external strong homogeneous constant magnetic field, in order to see what happens with electronic structure of (diatomic) molecule, is much important in view of the supposed magnetic origin of the bonds.

The most interesting is to investigate the electronic structure of many-electron diatomic molecules, especially CO (255.8 kcal/mol). A peculiar property of the electronic structure of carbon monoxide CO is that each of the atoms, C ($1s^2 2s^2 2p^2$) and O ($1s^2 2s^2 2p^4$), has free (lone) pair of electrons. So, only six electrons among ten $2s$ and $2p$ electrons, namely, two electrons from C and four electrons from O, are used to form two standard

valence π -bonds and one standard valence σ -bond, within the framework of the molecular orbitals method. All these π - and σ -orbitals are very close to O while the lone pair of C is far from O. This lone pair has high energy, and can easily react with an element that accepts electrons. So, CO reveals electronic donor properties. This model of the CO bonds is approximate because of the use of pure $2s$ and $2p$ orbitals; more detailed picture can be obtained by hybridization of $2s$ and $2p$ orbitals.

5. Van der Waals bonds?

Three basic types of Van der Waals bonds are:

The orientational bond, which is due to the interaction of constant dipole moments, p_e , of molecules,

$$U_{ori} = -\frac{p_e^4}{24\pi^2\varepsilon_0^2kT} \frac{1}{r^6}. \quad (30)$$

The molecules tend to direct their dipole moments \vec{p}_e along one line to provide lower value of the total energy while heat makes a disorder. The above expression for the potential energy is valid for high temperature region.

The inductive bond, which is due to the induced electric polarization of molecules, is characterized by the potential energy,

$$U_{ind} = -\frac{\alpha p_e^2}{8\pi^2\varepsilon_0^2} \frac{1}{r^6}, \quad (31)$$

where α is polarization constant. For neighbor molecules "A" and "B", the induced dipole moment of the molecule "A" is $\vec{p}_e = \varepsilon_0\alpha\vec{E}$, where \vec{E} is electric field of the molecule "B". The polarization property of the molecule "A", characterized by a numeric value of the parameter α , depends mostly on the molecular volume of the molecule "A"; for nonpolar molecules, α does not depend on the temperature.

The dispersional bond, which is due to the interaction caused by correlated zero mode oscillations of two neighbor molecules, is characterized, in a linear approximation, by the potential energy,

$$U_{disp} = -\frac{e^4\hbar\omega_0}{32\pi^2\varepsilon_0^2a} \frac{1}{r^6}, \quad (32)$$

where $\omega_0 = \sqrt{a/m}$ is frequency of zero mode harmonic oscillations, and a is coefficient of elasticity.

The above three formulas are in SI units, where $\varepsilon_0 = 8.85 \cdot 10^{-12} \text{C} \cdot \text{N}^{-1} \cdot \text{m}^{-2}$ is the fundamental dielectric constant, $k = 1.38 \cdot 10^{-23} \text{J} \cdot \text{K}^{-1}$ is Boltzman constant, $e = 1.6 \cdot 10^{-19} \text{C}$ is charge of electron, $\hbar = 1.06 \cdot 10^{-34} \text{J} \cdot \text{sec}$, and r is a distance; $1 \text{ erg} = 10^{-7} \text{J}$; $1 \text{ kcal} = 4.1868 \cdot 10^3 \text{J}$. Usually, the effective distance of the Van der Waals attraction is about $10^{-9} \text{m} = 10 \text{Å} \simeq 20 \text{ bohrs}$, between centers of molecules. For the molecules having considerable constant dielectric moment (like H_2O and HCl), the orientational VdW interaction (30) is dominating while for the other molecules the dispersional VdW interaction (32) is a leading term. The Van der Waals bond, as a sum of the above three types of bonds, $U_{VdW} = U_{ori} + U_{ind} + U_{disp}$, is usually characterized by the binding energy $B_{VdW} = 0.1 \dots 10 \text{ kcal/mol}$.

An example is $B_{VdW} = 2.4 \text{ kcal/mol}$ for methane (CH_4) molecular crystal which has the melting temperature $T = -183\text{C}$. For the higher mass alkanes (ethane, propane, butane, etc.) the melting temperature increases almost linearly, up to $T = 66\text{C}$ for triacontane (number of C atoms in triacontane molecule is 30). So, the Van der Waals binding energy for triacontane molecular crystal is estimated to be about $2.4 \times (273 + 66)/(273 - 183) = 9 \text{ kcal/mol}$.

From this point of view, *measurement of the melting temperature of magnecules and precise measurement of the temperature range at which magnecules in magnecules begin to dissociate*, at normal pressure, are of much interest, and could give us experimental grounds for independent estimation of the value of $B[\text{magnecule}]$, in addition to (28).

The values $B_{VdW} = 0.1 \dots 10 \text{ kcal/mol}$ are too small, in comparison with $B[\text{magnecule}] > 20 \dots 25 \text{ kcal/mol}$, to conclude that the specific bonds in magnecule are due to the Van der Waals bonds alone. However, in general the Van der Waals bonds can be strong enough in some cases, e.g., for fullerene (C_{60}) molecular crystal and the above mentioned triacontane, to survive room (and higher) temperatures. That is, B_{VdW} can be of the order of 20 kcal/mol , as it is the case for fullerene crystals. So, in general we can not rule out the possibility that the origin of the specific bonds in magnecules are due to Van der Waals bonds.

Nevertheless, while for the molecules like C_{60} or triacontane it is more or less justified that they provide strong VdW bonds (about $9 \dots 20 \text{ kcal/mol}$) since they are molecules of big size with big number of atoms, for H_2 and CO diatomic molecules it is hardly the case; we expect the values $B_{VdW} = 0.1 \dots 5 \text{ kcal/mol}$ for H_2 and CO (magnecules). So, it seems that the specific bonds in

magnecule are not Van der Waals ones alone since they alone are too weak to fit the currently available experimental data.

Below, we consider briefly some aspects of the processes in PlasmaArcFlow reactor, in order to give a preliminary analysis of the conditions at which magnecules of magnegas are produced.

Strong external (electro)magnetic field may cause a deep rearrangement of the electronic structure of many-electron diatomic molecules, thus leading to capability to form additional and/or rearranged bonds. On the other hand, the influence of the external (electro)magnetic field might be a driving force in producing of $(CO)_n$, and other gaseous molecular complexes, in the PlasmaArcFlow reactor; notice that the constant dipole moment of CO is about 0.12 Debye, and for H_2 it is zero. Indeed, the presence of high molecular mass complexes with the specific bonds estimated due to (27) indicates that in the reactor there are specific conditions for *ordering* of elementary molecules to the complexes despite the effect of high temperatures. Temperature of liquid in the reactor is kept at about $T \simeq 70C$, and therefore characteristic temperatures of gas in big bubbles are $T \simeq 70...100C$. Very small bubbles are of high pressure and temperature which decreases as they expand and try to reach thermodynamical equilibrium with the liquid until they leave it. These very small bubbles have temperature higher than $T = 100C$, and the gas in them is of high pressure. It seems that the complexes are formed after this stage. Indeed, very high temperatures ($T > 1500C$) caused by the arc serve to dissociate molecules while in the lower temperature region, close to the arc, association of molecules (H_2 , CO, etc.) takes place.

So, we indicate six characteristic temperature ranges and associated regions:

1. Temperature of the underwater arc (DC, 30...40V, 500...1000A), $T > 1500C$. Dissociation of H_2O molecules (~ 110 kcal/mol), association of CO (~ 255 kcal/mol) and CO_2 molecules;
2. Temperature in the region close to arc, $800 < T < 1500C$. Association of H_2 (~ 104 kcal/mol) and H_2O molecules, the reaction (22);
3. Temperature in the region near the arc, $700 < T < 800C$. Very small bubbles of CO, H_2 , CO_2 , and H_2O gases, the reaction (23);
4. Temperature in the region near the arc, $150 < T < 700C$. Very small bubbles of CO, H_2 , CO_2 , and H_2O gases;

5. Temperature in the region near the arc, $100 < T < 150\text{C}$. Association of O_2 molecules and complexes (~ 30 kcal/mol due to (27)), small and big bubbles of CO , H_2 , CO_2 , O_2 , and H_2O gases;
6. Temperature in the region far from the arc, $70 < T < 100\text{C}$. Association of complexes (~ 30 kcal/mol due to (27)), water condensation, big bubbles of CO , H_2 , CO_2 , and O_2 gases leaving the liquid.

Here, we have not indicated C atoms which can also be present and make an essential contribution at some of the above stages.

Microscopically, forming of the high mass metastable complexes requires collision, or series of collisions, of several CO (and may be H_2 and O_2) molecules, at temperatures $T < 150\text{C}$. Otherwise, the complex would be dissociated back by heat excitations. However, we should to note that high pressure in bubbles can admit higher temperatures, $T < 200\text{C}$, or so, instead of $T < 150\text{C}$.

8 Conclusions

Magnegas are essentially composed of metastable clusters, called Santilli's magnecules [1c], containing isolated H, C, and O atoms plus OH, CH dimers, plus H_2 molecules, single, double, and triple CO bonds.

The initiation of the combustion breaks down those clusters after which some of H atoms form H_2 molecules while other form H_2O without forming H_2 molecules. It is important to note that prior to combustion, only a small number of C and O atoms are combined into carbon monoxide. As established by experimental evidence, CO_2 is contained in the exhaust in about 5%. This evidence is particularly intriguing in view of the fact that 50% of magnegas produced from pure water and carbon electrodes must be composed of C and O atoms. The fact that the combustion exhaust of the same gas contains about 5% CO_2 therefore establishes beyond doubt that only a small percentage of C and O atoms are bonded into carbon monoxide. Still in turn this evidence establishes magnecular structure of magnegas.

In view of all the above results the combustion of magnegas can be optimized by the following means:

- 1) Magnegas combustion should run at lower temperatures as compared to other fuels. In particular, this implies automatical reduction of NOx 's;

2) Combustion of magnegas should be triggered by spark operating at the highest possible voltage with a minimum of the order of 50,000 V;

3) Energy content of magnegas can be increased with increase of operating pressure and electric power.

In closing, we should indicate that the number of open problems on the creation, structure and combustion of magnegas has increased, rather than decreased, following this study. This outcome should have been expected in view of the novelty, extreme complexities, as well as insufficient experimental data at this writing on the magnegas technology.

It is hoped that this study will stimulate additional research by interested colleagues in view of the important environmental implications of this new fuel.

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