

Preparation and Study of Renewable Solid Powder Fuel for Duct engines

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ABSTRACT: This paper is a conceptual proposal on preparation and study of a solid powder fuel for Duct engines. Crude oil is non-renewable which is running out and the unleaded kerosene production has become difficult. This renewable solid powder fuel is used as an alternative for the existing liquid fuels in aviation industry. We developed a renewable fuel which is in the form of solid powder, which can be sprayed into the combustion chamber of duct engines. Generally, in duct engines compressed air is used as a burning medium and oxidizer, whereas Solid fuels are not used in duct engines. This study includes the determination of calorific values of coal with different densities and comparing them with the aviation fuel calorific values. Efficient additives are added to the coal obtained from *Prosopis juliflora* to increase its calorific value. We studied the heat of formation of the final product which is renewable solid powder for duct engines.

Keywords: Renewable coal, *Prosopis juliflora*, Duct engines, Powder spraying technology, Combustion chamber materials, Heat of formation, Additives .

I. INTRODUCTION:

A propellant is a material that is used to move an object by applying a motive force. This may or may not involve a chemical reaction. It may be a gas, liquid, plasma, or, before the chemical reaction, a solid. Common chemical propellants

consist of a fuel, like gasoline, jet fuel and rocket fuel, and an oxidizer.

Fuel is a material which releases heat energy when it burns in presence of air. Fuel is a chemical compound which releases heat when it burns. Propellant is mixture of chemical compounds mainly consisting of oxidizer and fuel and sometimes burning catalysts.

Solid fuel refers to various forms of solid material that can be burnt to release energy, providing heat and light through the process of combustion. Solid fuels can be contrasted with liquid fuels and gaseous fuels. Common examples of solid fuels include wood, charcoal, peat, coal, hexamine fuel tablets, wood pellets, corn, wheat, rye, and other grains. Solid fuels are extensively used in rocketry as solid propellants. Solid fuels have been used throughout human history to create fire and solid fuel is still in widespread use throughout the world in the present day.

Wood fuel can refer to several fuels such as firewood, charcoal, wood chips sheets, pellets, and sawdust. The particular form used depends upon factors such as source, quantity, quality and application. In many areas, wood is the most easily available form of fuel, requiring no tools in the case of picking up dead wood, or few tools. Today, burning of wood is the largest use of energy derived from a solid fuel biomass.

Advantages of solid fuels:

Advantages of solid fuels	
•	They are easy to transport.
•	They are convenient to store without any risk of spontaneous explosion.
•	Their cost of production is low.
•	They possess moderate ignition temperature.

Disadvantages of solid fuels:

Disadvantages of solid fuels	
•	Their ash content is high.
•	They burn with clinker formation.
•	Their combustion operations cannot be controlled easily.
•	Their cost of handling is high.
•	Their large proportion of heat is wasted during combustion.
•	Their thermal efficiency is low.
•	Their calorific value is lower as compared to that of liquids fuels.
•	They require a large excess of air for complete combustion.
•	They cannot be used as internal combustion engine fuels.

Fuel additives:

Fuel additives are compounds formulated to enhance the quality and efficiency of fuels used in motor vehicles. They increase a fuel's octane rating or act as corrosion inhibitors or lubricants, thus allowing the use of higher compression ratios for greater efficiency and power. Fuel additives can help to avoid problems such as rough idling, weak acceleration, stumbling and stalling.

Fuel additives are available in a number of forms, such as liquid, powder or pill. They work in a number of different ways and claim to do various things to the fuel, including:

- Remove sludge
- Control soot
- Improve combustion
- Act as a biocide

Explosive is a material which causes an explosion. An explosion is a rapid expansion in volume associated with an extremely vigorous outward release of energy, usually with the generation of high temperatures and release of high-pressure gases. Supersonic explosions created by high explosives are known as detonations and travel via shock waves. Subsonic explosions are created by low explosives through a slower combustion process known as deflagration.

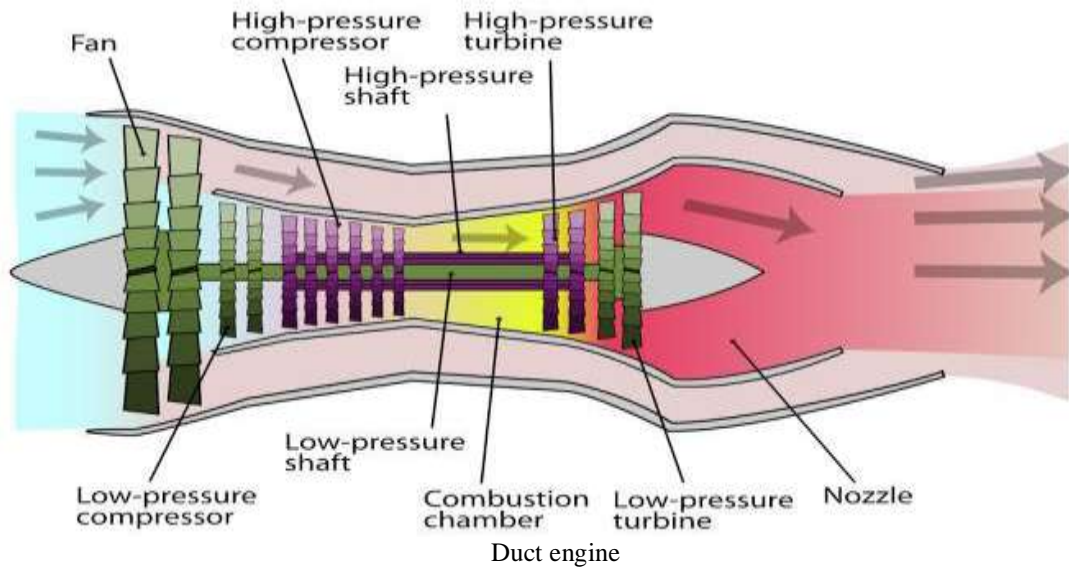
- Nitrocellulose

- Nitroglycerin
- Nitroguanide
- Ammonium Nitrate
- Aluminium powder
- GAP(Glycidyl azide polymer)
- Urea nitrate
- PGN(Propyl glycidyl nitrite)
- Bis-(azidomethyleoxetane)
- Nitromethyl oxetane
- Aluminium perchloride
- HTPB(Hydroxyl Terminated Polybutadiene)
- RDX(hexahydro-1,3,5-trinitro-1,3,5-triazine)
- HMX(Octogen) etc.

Burning catalysts are used to control the combustion reaction.

- Potassium nitrate
- Ferric oxide
- Hydrate ferric oxide
- n-butyl ferrocene
- di-n-butyl ferrocene
- Lithium fluorite etc.

Duct Engine is an air breathing and turbine engine. It works on brayton cycle. Fluid fuel and compressed air as oxidizer are used. Compressed air is also burning medium. Fluid fuel sprays or injected into the burning medium which is already heated up to above the flash point of the fuel.



Powder spraying technology:

This is the technology in existence in various fields like agriculture, printing, painting, production, etc. This concept's proposal is to use this powder spraying technology to spray the fuel in powder form into the combustion chamber of duct engine.

According to this powder spraying mechanism, the powder in fine form can be mixed with compressed air. This air powder mixture can be a fluid until it flows. So this mixture fluid can be sprayed finely. In the proposed technique the air powder mixture will be the fluidic fuel. The solid powder fuel is converted into a fluid by adding air and kinetic energy. This fluid can replace the liquid fuel in duct engines. And the air powder mixture

fuel will be sprayed into the compressed air in the combustion chamber.

The use of high velocity thermal spraying as a method to form plain bearings for automotive engine applications was developed by a consortium of partners (that included the authors of this presentation) in a project funded by the DTI Surface Engineering LINK programme. Further development has led to a widening in the range of bearing alloys deposited by this method, together with the launch of a commercial product by Glacier Vandervell. The presentation will give a brief summary of this approach to bearing production and highlight some of the more recent developments.



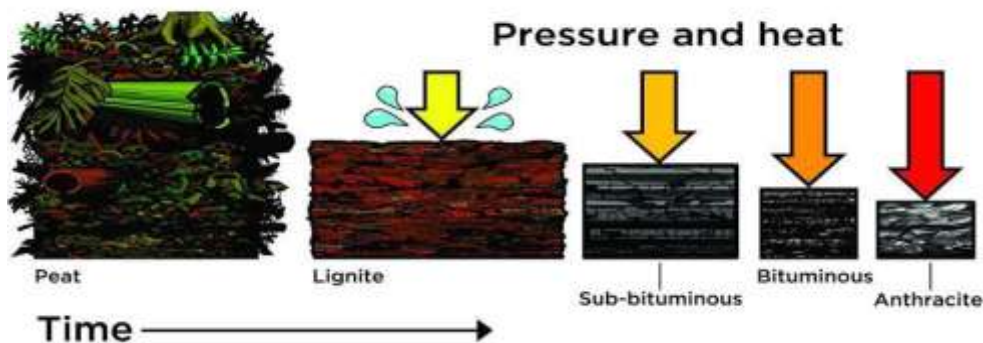
Powder spraying equipment

II. METHODOLOGY:

Coal:

Coal is a combustible black or brownish-black sedimentary rock with a high amount of carbon and hydrocarbons. Coal is classified as a nonrenewable energy source because it takes

millions of years to form. Coal contains the energy stored by plants that lived hundreds of millions of years ago in swampy forests. Layers of dirt and rock covered the plants over millions of years. The resulting pressure and heat turned the plants into the substance we call coal.



Process of formation of natural coal

Prosopis juliflora:

Prosopis juliflora is a shrub or small tree in the family Fabaceae, a kind of mesquite. Today, it is vilified as an invasive tree that causes enormous damage to the environment and inhibits the growth of indigenous plants. But in the early 1960s, when Tamil Nadu was reeling under a

severe shortage of firewood and the issue even triggered a debate in the Legislative Assembly, prosopisJuliflora, known as seemaikaruvelam, was seen as a saviour to overcome this shortage. It even earned the sobriquet panjamthaangi (providing succour during famine).



Prosopis juliflora tree

The then Congress government, led by Chief Minister Kamaraj, made arrangements for aerial seeding of the plant from a helicopter in Ramanathapuram district. The authorities in other districts advised people to plant the tree in

poromboke land, tank bunds and natham land to overcome the firewood shortage. The tree was also used to erect fences, making it difficult for animals to invade agricultural fields.

With cooking gas and kerosene replacing firewood even in remote villages, the role of seemaikaruvelam as a provider of firewood has almost come to an end. But, the tree has entrenched itself in the soil, spreading its roots like the tentacles of a mythical animal.

Though the plant gained popularity in the 1960s, seemaikaruvelam actually arrived almost a century ago. According to the Food and Agriculture Organisation (FAO) of the United Nations, Lt. Col. R.H. Bendome, Conservator of Forests of Northern circle (Madras), was responsible for its introduction. He had requested the Secretary of the Revenue department of Madras to supply seeds of the plant for planting in arid tracts of South India in 1876. The seeds were received from Jamaica and sown in South India during 1877.

Even in 1953, the Fodder and Grazing Committee of Madras decided to grow seemaikaruvelam on a large scale on the slopes of barren hills and panchayat forests to augment fuel supply. In fact, The Hindu archives have an advertisement placed by a nursery in T. Nagar selling the tree's seeds. While various species of *Prosopis* were introduced at the time, *Prosopis juliflora* has spread over large areas and has naturalized in most of the arid and semi-arid regions of India.

"*Prosopis juliflora* has survived where other tree species have failed, and in many cases, become a major nuisance. It has invaded, and continues to invade, millions of hectares of rangeland in South Africa, East Africa, Australia and coastal Asia. In 2004, it was rated one of the world's top 100 least wanted species.

India covers an area of 3.29 million km². Of this total, 51% is characterized as arable land, 16% as forest, 4% as permanent pasture and other grazing land, and 29% as degraded land unsuitable for cultivation. The eco-climate of the country varies from extreme arid to super humid. The arid and semi-arid regions together constitute over 40% of the country's total land surface and are spread over ten States. The climatic conditions in these areas do not support much growth and regeneration of plant species. Consequently, the vegetation is quite sparse. The forest cover in arid and semi-arid tracts of India varies from 1 to 10%. Furthermore, the forests in these regions are not species rich. From time immemorial, human populations in arid and semi-arid regions have used the forest/woody resources freely for subsistence agriculture and for other small-scale economic activities like ironworking and carpentry. Trees in the farming systems of arid and semi-arid tracts supply

considerable amounts of timber, fuel and fodder. However, with ever increasing human and livestock population pressure during the last half century, deforestation has reached an alarming stage. This state of affairs has created a wide gap between the demand and supply of forest products.

Since wood remains the main source of cooking fuel for about 70% of the population, it is obvious that much of the wood comes from illegitimate felling and cutting of trees. Though this trend is similar for the entire country, it is particularly so in arid and semi-arid regions. Since colonial times, planners, policy makers and forestry experts have given much emphasis to introducing fast growing and well adapted exotic woody species from iso-climatic regions of the world into arid and semi-arid India. Some of these exhibited remarkable adaptability and growth in their new habitats. *Prosopis juliflora* (Swartz)DC is one of these species that has performed much better than many native woody species. At the moment, *P. juliflora* provides approximately 75% of the fuelwood needs of rural people in arid and semi-arid regions of India. The species has become naturalised and has spread over the greater part of north-west, central, west and south India. With its tremendous ability to adapt to arid and semi-arid environments, and its fast growth and multiple utility, it has long been recognised by foresters as a versatile species for afforestation. However, rural people in arid and semi-arid regions of India are a little apprehensive of this species as (i) they consider that the species adversely affects crop growth and production; (ii) there is a fear that it may become a weed; and (iii) the thorny stems and branches of the species often cause injury to humans and animals, and hinder agricultural operations. Whatever advantages and disadvantages may be associated with the species, *P. juliflora* has become a prominent woody species in agro-ecosystems of arid and semi-arid regions of India. The species is used widely in plantation forestry activities in wastelands, village common lands, grazing lands, along railway lines and roads, canal and village pond banks, and degraded forested lands. Moreover, natural regeneration is profuse throughout the entire arid and semi-arid regions of the country. Although *P. juliflora* is of great importance to most rural communities in arid and semi-arid tracts of India, its full potential in the rural forestry sector has not been realised to the extent that it deserves. In particular there is a need to increase the level of information related to plantation, successfully marketed *P. juliflora* and *P. pallida* tree products. Management and utility of this multipurpose species among rural communities

and developmental agencies such as state forest departments, agriculture departments, district rural developmental agencies and non-governmental organisations. This technical manual on *Prosopis juliflora*

provides basic information and guidance to rural people and to those who instruct farmers and land managers on the use of this species in various environments and agricultural settings.



Charcoal production from *Prosopis juliflora* a) harvested stem wood lots b) harvested wood arranged for controlled burning c) charcoal from root wood and d) charcoal final product ready for domestic and industrial use.

The history of the first introduction of *Prosopis juliflora* into India is about 130 years old. Introduction of the species was first seriously attempted in 1870. Owing to its fast growth and drought hardiness, the species has since been introduced in many other parts of India from the north-west to extreme southern parts. The species proved its potential as a versatile plantation forestry species from the very first introduction and has been grown in highly saline areas, alkaline soils, coastal areas, sand dunes of the Thar desert, in ravines of many north, central and south Indian rivers, and in dry and degraded grasslands. *P. juliflora* has become an acclimatised exotic in large parts of arid and semi-arid tropical India (Figure 2). It is found especially in areas with 150-750 mm mean annual rainfall and maximum shade temperatures of 40-45°C. From north-west to south, the species is distributed from the States of Punjab to Tamil Nadu, and in an east-west direction, it is found from Kutch region of Gujarat

State to drier parts of Orissa. The States where it mainly occurs are: Andhra Pradesh, Delhi, Haryana, Karnataka, Madhya Pradesh, Maharashtra, Punjab, Rajasthan, Tamil Nadu and Uttar Pradesh. The domain of the species in arid and semi-arid tropical regions is mostly in plains and valleys but in many places it grows at altitudes of up to 1200 m above mean sea. The potential for *Prosopis*. Salt affected lands in India account for ten million hectares (ha). Thirteen million ha of wastelands in arid and semi-arid tracts can support plantations of drought hardy woody species. Thus, 23 million are readily available for plantations of *P. juliflora*. Considering an average production (a conservative estimate) of about 3 m³ per ha, the annual production could be approximately 70 million m³, which represents about 250% of the current annual production of fuelwood from forest resources in the country. *P. juliflora* is capable of growing in a wide variety of soils and situations. It is, however, generally not found in frost prone

areas, the Himalayan region or in warm humid tracts such as the northeastern region, West Bengal and Kerala. However, in Kerala, and

2. Distribution of *P. juliflora* in India. Also in Bihar and Orissa, farmers use the species as a live fence around fields and farms. The most abundant distribution of this species is found in the Kutch region of Gujarat, the arid western part of Rajasthan, western and south-central parts of UP, the western part of Haryana, and in a few pockets of extreme north Andhra Pradesh. In its entire range of distribution, thickets of the species are found here and there in a variety of habitats and settings. Block plantations of the species are very few but the species is planted systematically along road sides, railway lines, canal banks.

Making of coal from wood:

The process of making charcoal is ancient, with archaeological evidence of charcoal production going back about 30,000 years. Wood charcoal has been used since earliest times for a large range of purposes including cooking, medicine, art, metallurgy, industry etc. The raw material for wood charcoal could be wood chips, branches, saw dust, agricultural wastes etc.

Wood charcoal is mostly pure carbon, called char (the first syllable of charcoal), made by heating wood above 400° C in a low oxygen environment. The process, called pyrolysis, can take days and burns off volatile compounds such as water, methane, hydrogen, and tar. There are some methods that burn the volatile gasses to prevent them from escaping as pollution and producing surplus heat, other methods collect them for later use as biofuels.

The manufacturing of charcoal is a multi-step process that requires control of the various factors that could affect the process: the wood used, heating temperature, air availability, and time of processing. In commercial processing, the burning takes place in large concrete or steel kiln, which is almost three meters in diameter and a little over a meter in height. Once the dry wood is split into smaller pieces and stacked loosely almost to the top of the charcoal chamber, the kiln is closed and covered with an insulation layer. A small fire is started in the combustion chamber and soon the chimney begins to produce very wet, low temperature steam. The purpose of maintaining this fire is twofold, to create heat for driving out water and impurities, and to use up the oxygen coming into the kiln. Depending on the size of the wood

inside, after a while the smoke changes to bluish and almost clear, what means that the water is gone and the wood should be mostly converted to charcoal. The process leaves black lumps and powder, about 25% of the original weight. It takes about 14-16 hours and produces ready-to-use lump charcoal. It should be noted that if the kiln is opened while the charcoal is still hot, it will burst into flame and all of the charcoal will turn to ash.

But charcoal briquettes are not pure charcoal. At the beginning of the charcoal-making process, that mountain of wood glides onto conveyer belts and enters a wood hog that feeds the retort for char. Afterward, it is dried and then packaged. The charring process occurs when the wood is burned in a furnace, creating a manageable material to form into a briquette. When the charcoal is warm and soft, it is put into a dryer set at 300 ° C. After a while the once-soft briquettes come out hard and are ready to be bagged.

Black charcoal or “domestic charcoal” is soft and retains the outer layer of the wood. It is also easy to ignite and burns hot enough that it was used as fuel for tea ceremony, and ordinary daily food cooking including industrial use during the former times. Standard charcoal is good and highly flammable.

As opposite to black charcoal, white charcoal or “hard charcoal” is made by carbonizing the wood at a moderately low temperature, then, near the end of the process, the kiln temperature is raised to around 1000 °C in order to make the wood red hot. Than white charcoal must be removed from the kiln and quickly smothered with a covering of powder to cool it. The powder is a mixture of sand, earth, and ash that will give a whitish color to the surface of the charcoal. White charcoal may take some more time to ignite, but its thermal conductivity is way better than ordinary black charcoal. The flame produced by white charcoal lasts long enough to be used as fuel.

So, nowadays wood charcoal is not only fuel for cooking, but it is used in metallurgy, medicine, art, industry etc. The process of making wood charcoal is multilevel and requires control of a lot of factors, such as time, temperature, materials and air availability. Depending on these factors there are charcoal briquettes and lumps, as well as white and black charcoal. So, taking into account useful qualities of charcoal it must be said that it is going to be used much more intensively.



Coal furnace



Grinding of coal into a fine powder

Typical steps in coal preparation include:

- Crushing
- Screening into different size fractions
- Physical, chemical or mechanical processes to remove undesired impurities
- Dewatering
- Thermal drying
- Blending
- Agglomeration

Coal processing is important:

- Remove extraneous, non-combustible material
- Ash reduction
- Lower particulates
- Reduced ash handling at power station
- Sulfur reduction
- Carbon emission reduction
- Reduced transportation costs per unit of heat
- Guaranteed consistent heat value

- Improved plant efficiency

Heat of formation:

Heat of formation, also called standard heat of formation, enthalpy of formation, or standard enthalpy of formation, the amount of heat absorbed or evolved when one mole of a compound is formed from its constituent elements, each substance being in its normal physical state (gas, liquid, or solid). Usually the conditions at which a compound is formed are taken to be at a temperature of 25 °C (77 °F) and a pressure of 1 atmosphere, in which case the heat of formation can be called the standard heat of formation. The heat of formation of an element is arbitrarily assigned a value of zero. By using Hess's law of heat summation, one can calculate the heat absorbed or evolved in any chemical reaction by summing the known heats of formation or combustion for the steps in that reaction.

$$\Delta_r H^\ominus = \sum v \Delta_f H^\ominus (\text{products}) - \sum v \Delta_f H^\ominus (\text{reactants})$$

$\Delta_f H^\ominus$	= standard enthalpy of formation for a chemical reaction at standard temperature and pressure (STP)
v	= coefficients of each respective reactant or product in the balanced chemical reaction
$\Delta_f H^\ominus (\text{products})$	= sum of enthalpy of each individual product in the balanced chemical reaction
$\Delta_f H^\ominus (\text{reactants})$	= sum of enthalpy of each individual reactant in the balanced chemical reaction

The standard enthalpy of formation or standard heat of formation of a compound is the change of enthalpy during the formation of 1 mole of the substance from its constituent elements, with all substances in their standard states. The standard pressure value $p^\ominus = 105 \text{ Pa} (= 100 \text{ kPa} = 1 \text{ bar})$ is recommended by IUPAC, although prior to 1982 the value 1.00 atm (101.325 kPa) was used. There is no standard temperature. Its symbol is $\Delta_f H^\ominus$. The superscript Plimsoll on this symbol indicates that the process has occurred under standard conditions at the specified temperature (usually 25 °C or 298.15 K). Standard states are as follows:

For a gas: the hypothetical state it would have assuming it obeyed the ideal gas equation at a pressure of 1 bar

For a solute present in an ideal solution: a concentration of exactly one mole per liter (1 M) at a pressure of 1 bar

For a pure substance or a solvent in a condensed state (a liquid or a solid): the standard state is the pure liquid or solid under a pressure of 1 bar.

For an element: the form in which the element is most stable under 1 bar of pressure. One exception is phosphorus, for which the most stable form at 1 bar is black phosphorus, but white phosphorus is chosen as the standard reference state for zero enthalpy of formation.

Hess law:

For many substances, the formation reaction may be considered as the sum of a number of simpler reactions, either real or fictitious. The enthalpy of reaction can then be analyzed by applying Hess's Law, which states that the sum of the enthalpy changes for a number of individual reaction steps equals the enthalpy change of the overall reaction. This is true because enthalpy is a state function, whose value for an overall process

depends only on the initial and final states and not on any intermediate states. Examples are given in the following sections

The standard enthalpy change of any reaction can be calculated from the standard enthalpies of formation of reactants and products using Hess's law. A given reaction is considered as the decomposition of all reactants into elements in their standard states, followed by the formation of all products. The heat of reaction is then minus the sum of the standard enthalpies of formation of the reactants (each being multiplied by its respective stoichiometric coefficient, v) plus the sum of the standard enthalpies of formation of the products (each also multiplied by its respective stoichiometric coefficient), as shown in the equation below.

$$\Delta H_{\text{reaction}}^\ominus = \sum \Delta H_f^\ominus (\text{products}) - \sum \Delta H_f^\ominus (\text{Reactants})$$

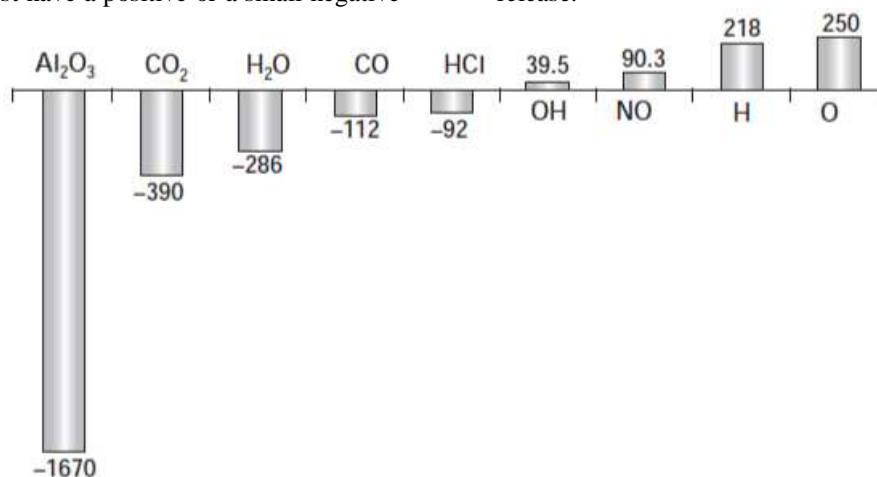
If the standard enthalpy of the products is less than the standard enthalpy of the reactants, the standard enthalpy of reaction is negative. This implies that the reaction is exothermic. The converse is also true; the standard enthalpy of reaction is positive for an endothermic reaction. This calculation has a tacit assumption of ideal solution between reactants and products where the enthalpy of mixing is zero. The heat released from combustion of the propellants.

$$\Delta H_c = - \left[\sum_{\text{Products: } i=1}^N v_i'' \Delta H_{f, M_i}^\ominus - \sum_{\text{Reactants: } i=1}^N v_i' \Delta H_{f, M_i}^\ominus \right]$$

It is seen from the above equation, that the heat of formation of Δ_{hof} of the products of combustion of the propellants must be large and

negative while the propellants themselves (reactants) must have a positive or a small negative

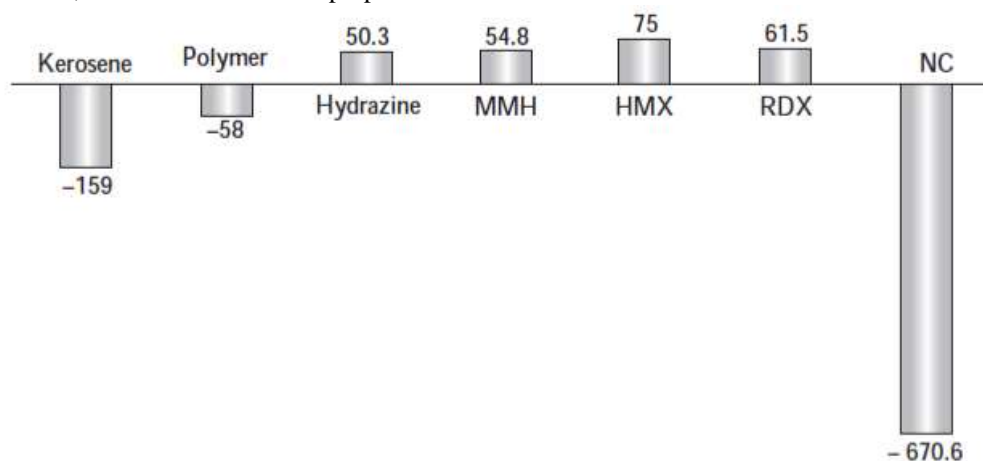
value of Δh_{of} in order to obtain maximum heat release.



Heat of formation in KJ/mol of some typical products of combustion

The values of Δh_{of} for typical products of combustion are given in Figure. It is seen that the completely oxidised substances, e.g. CO₂, H₂O and Al₂O₃ have large negative values of Δh_{of} . It would, therefore, be desirable that the propellants

used and the mixture ratios are such that these completely oxidised substances are formed during the combustion as against the under-oxidised CO and the dissociated products, such as, OH, H and O.



Heat of formation in KJ/mol of some typical propellants(fuels)

The heats of formation of a few propellants comprising fuel, oxidiser or a combination of fuel and oxidiser (explosive) are shown. It is seen that the propellant hydrazine (N₂H₄) and explosives, such as, RDX and HMX have positive heats of formation. RDX and HMX are cycloaliphatic compounds. RDX is cyclotrimethylenetrinitramine [(CH₂)₃(NNO₂)₃] while HMX is cyclotetramethylene tetra nitramine [(CH₂)₄(NNO₂)₄].

We shall consider these explosives, which are fuel-rich, while studying solid propellants.

Substances having positive heat of formation, though suited from considerations of energy release, are generally unstable and tend to react spontaneously and are, therefore, hazardous. The trend, therefore, is to choose the reacting propellants with rather small negative values of Δh_{of} . Solid oxidisers, such as, ammonium perchlorate (AP) and nitroglycerine (NG), solid fuel consisting of polymers and nitrocellulose (NC), liquid fuels, such as, kerosene and liquid oxidisers, such as, dinitrogen tetroxide (N₂O₄) and nitric acid (HNO₃), find application as oxidisers and fuels. Substances which are elements at the standard state, such as, hydrogen, oxygen, metal

aluminum, metal boron, etc., having $\Delta_f H^\circ = 0$ are also well suited. Hydrazine (N_2H_4) and mono-methyl hydrazine (MMH – $CH_3N_2H_3$) have mildly

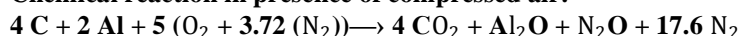
positive values of $\Delta_f H^\circ$ and are widely used since they do not spontaneously react.

Experimentation:

S.No	Chemical name	Type	Percentage(%)
1	Renewable charcoal	Base fuel	66.8
2	Aluminium powder	Additive	33.2

List of chemicals in fuel with percentage

Chemical reaction in presence of compressed air:



Enthalpy of reactants and products:

Sl. No.	Reactant or Product	$\Delta_f H^\circ$ Enthalpy of Reactant or product (in KJ/mol)
1	C	0
2	Al	0
3	CO_2	-393.5
4	N_2	0
5	N_2O	82.05
6	Al_2O_3	-1620.57

List of enthalpies of reactants and product

Calculations:

$$\Delta_r H^\circ = \sum_v \Delta_f H^\circ(\text{products}) - \sum_v \Delta_f H^\circ(\text{reactants})$$

$$\Delta_r H^\circ \text{ of } 4C+2Al = [4 \text{ mol} \times -393.5 \text{ KJ/mol} + 1 \text{ mol} \times -1620.57 \text{ KJ/mol} + 1 \text{ mol} \times 82.05 \text{ KJ/mol} + 1 \text{ mol} \times 0 \text{ KJ/mol}]$$

$$- [1 \text{ mol} \times 0 \text{ KJ/mol} + 2 \text{ mol} \times 0 \text{ KJ/mol} + 5 \text{ mol} \times -393.5 \text{ KJ/mol} + 3.72 \text{ mol} \times 0 \text{ KJ/mol}]$$

$$= [-1574 + (-1620.57) + 82.5 + 0] - [0 + 0 + (-1967.5) + 0]$$

$$= [(-3112.52) - (-1967.5)]$$

$$= -1145.02 \text{ KJ/mol}$$

III. RESULTS AND DISCUSSION:

Heat of formation of $4C+2Al = -1145.02$ KJ/mol

Negative heat of formation indicates that the energy is released and the reaction is exothermic. Fuels heat of formation will give a negative value. When a substance undergoes

combustion it releases energy. Combustion is always exothermic, the enthalpy change for the reaction is negative and the heat of combustion will be a positive value. According to the results obtained from the calculations the prepared powder material is a fuel and it is better than kerosene. So this is a better fuel which is renewable and can be used as an alternative fuel.

IV. CONCLUSION:

We can conclude that the obtained solid powder ($4C+2Al$) fuel is a bio related renewable alternative fuel which may satisfy the fuel needs of the transportation industry. Because today's world is looking at an alternative, bio and renewable fuels. Because of the increase in air pollution and the cost of aviation fuels. Chemical propulsion can only give effective and efficient performance but cannot decrease the air pollution. The solid powder fuel which we obtained can satisfy the above requirements and it is eco friendly. The thermo chemical properties of the fuel are also good.

So, this solid powder fuel ($4C+2Al$) which is obtained may replace the conventional and

existing liquid fuels in duct engines after a long research and development.

REFERENCES

- [1]. George P. Sutton , "Rocket Propulsion Elements", Oscar Biblarz, 2016.
- [2]. Dr. Jai Prakash Agrawal, "Organic Chemistry of Explosives", John Wiley and sons, 2007.
- [3]. David A. Tillman, "Solid Fuel Blending", B/H.
- [4]. Shalini Chaturvedi & Pragnesh N Dave, "Solid Propellants: AP/HTPB composite propellants", Esilver.
- [5]. Tim Edwards¹, "Evaluation of Combustion Performance of Alternative Aviation Fuels", Dayton OH 45433.
- [6]. George R. Wilson, "Alternative Aviation Fuels and Blend Components", Alicia Benhidjeb-Carayon.
- [7]. Dewei Wang , "Gunpowder chemistry-assisted exfoliation approach for the synthesis of porous carbon nanosheets for high-performance ionic liquid based supercapacitors", Jiawang Nai.
- [8]. M.J. Kamlet, "The Relationship of Impact Sensitivity with Structure of Organic High Explosives. 11. Poly Nitroaromatic Explosive", Esilver.
- [9]. KOTAS MAKRIS, URL: <http://www.kostasmakris.com> .
- [10]. Timmat, Y., "Advanced Chemical Rocket Propulsion", Academic Press, 1987.
- [11]. K Ramamurthy, "Rocket Propulsion", Trinity Press, 2008.
- [12]. Jacqueline Akhavan, "The Chemistry of Explosives", Royal society of Chemistry, 2011.