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לשכת המהנדסים
האדריכלים והאקדמאים
במקצועות הטכנולוגיים
בישראל

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טכנולוגיות הנעת כלי טיס
בלתי מאוישים

הכנס הארצי השמיני

חוברת תקצירים

הפקולטה להנדסת מכונות, הטכניון
חיפה
כ"ה שבט תשע"ט
31 בינואר 2019

Conference Program

8th Conference on Propulsion Technologies for Unmanned Aerial Vehicles

Thursday, January 31, 2019
Shirley and Manny Ravet Auditorium, D. Dan and Betty Kahn Building
Faculty of Mechanical Engineering, Technion, Haifa

8:30 – 9:00	**Welcome and Registration**
Opening session	**Chairman: Leonid Tartakovsky,** Technion
9:00 – 9:30	**Welcome:** ***Anath Fischer,*** Deputy Executive Vice President for Research, Technion ***Oleg Gendelman*****,** Dean, Faculty of Mechanical Engineering, Technion ***Yigal Ben-Shabat*****,** Head, Propulsion Branch, Directorate of Defense Research & Development, MAFAT ***Emanuel Liban*****,** Chairman, Israel Society of Mechanical & Aerospace Engineers
9:30 – 10:00	**Keynote lecture:** **Future engine fuels and their implications** ***Jaal Ghandhi*****,** Chairman, Department of Mechanical Engineering, University of Wisconsin-Madison, USA
Plenary session 1	**Chairman: Yitzhak (Itche) Hochmann,** Edmatech
10:00 – 10:30	**Using advanced batteries for propulsion: scope of options** ***Doron Aurbach*****,** Bar-Ilan University
10:30 – 11:00	**Research Activities, Challenges, and Future Directions in UAV Propulsion** ***Michael Kass*****,** Fuels and Engines Group, Oak Ridge National Laboratory, USA
11:00 – 11:30	**Coffee break**
Plenary session 2	**Chairman: Michael Shapiro,** Technion
11:30 – 12:00	**Guide to design of efficient UAV propulsion** ***Emanuel Liban*****,** CEO, Edmatech, Israel
12:00 – 12:20	**High Power Density High Efficiency Mechanically Assisted Turbocharged Direct Injection Jet Ignition Engines for Unmanned Aerial Vehicles** ***Albert Boretti*****,** Independent Scientist, Australia
12:20 – 12:45	**UAV propulsion from the viewpoint of an operator** **G. Sheffy,** Israel Air Forces, IDF, Israel
12:45 – 12:55	**Best Student Poster Award Ceremony**
12:55 – 14:00	**Lunch**
Session "New Concepts "	**Chairman: Ariel Dvorjetski,** IDF Shirley and Manny Ravet (big) Auditorium

14:00 – 14:20	**In-Cylinder Steam Reforming in UAV Diesel Engines** ***Ilai Sher***[1], ***Eran Sher***[2], 1 – Ontario, Canada; 2 - Technion, Israel
14:20 – 14:40	**Laser Energy Transfer – Preliminary Experimental Results** ***Igor Gerlovin***, Israel Aerospace Industries
14:40 – 15:00	**High-pressure thermochemical recuperation of exhaust gas energy in internal combustion engines** ***Arnon Poran***[1,2], ***Leonid Tartakovsky***[2], 1 – Rafael, 2 – Technion, Israel
Session "Engine Design & Performance – 1"	**Chairman: Jacob Feldman,** Israel Aerospace Industries Andrew Davidovits (small) Auditorium
14:00 – 14:20	**The Elbit Systems 903 Next Generation Rotary Engine: From Simulation to Prototype** ***Guy Ben-Haim***, ***Nir Geva,*** Elbit Systems, Israel
14:20 – 14:40	**Performance comparison of a direct-injection ICE in diesel and spark-ignition operation with methanol reforming products** ***Andy Thawko***, ***Leonid Tartakovsky***, Technion, Israel
14:40 – 15:00	**Mechanisms of rotational speed control for propellers with a constant pitch** ***Aviv Turgeman***, Aeronautics, Israel
15:00 – 15:20	**Coffee break**
Session "Alternative Propulsion Technologies"	**Chairman: Igor Gerlovin,** Israel Aerospace Industries Shirley and Manny Ravet (big) Auditorium
15:20 – 15:40	**Fuel Cells Technology for UAVs** ***Lior Elbaz,*** Head of the Israeli Fuel Cells Consortium, Bar-Ilan University
15:40 – 16:00	**CFD simulation of ethanol steam reforming for external combustion engine** ***Alon Davidy,*** TOMER Co., Israel
16:00 – 16:20	**Maintenance of electric propulsion systems** **Erez Mosafi,** Ledico – Bosch, Israel
Session "Engine Design & Performance – 2"	**Chairman: Benjamin Brinder,** IDF Andrew Davidovits (small) Auditorium
15:20 – 15:40	**Propulsion System Availability Improvement by Advanced Health Monitoring Techniques** ***Netanel Dabush***, ***Idan Biner,*** Aeronautics, Israel
15:40 – 16:00	**Electro-Magnetic Interference and the UAV Power Plant** ***Jonathan Nassau***, ***Menachem Lerer***, Elbit Systems, Israel
Closing remarks 16:20 – 16:30	**Leonid Tartakovsky**, Chairman Organizing Committee Shirley and Manny Ravet (big) Auditorium

Posters session

1. **Numerical Simulation and Parametric Investigation of Boron Loaded Gel Fuel Ramjet**
   David Diskin, Benveniste Natan, Technion - IIT, Israel.
2. **HCCI Combustion Process Management in ICE with TCR by Control of the Methylal Reforming Products Composition**
   Denis Buntin, Leonid Tartakovsky, Technion – IIT, Israel
3. **Pump Based Hydrogen Generator**
   Michael Zolotih, Lev Zakhvatkin, Idit Avrahami, Alex Schechter, Ariel University, Israel
4. **Storage ageing of grease in sealed-for-life high speed rolling bearings**
   Y. Kligerman[1], *H. Kasem*[1,2] *and M. Varenberg*[3], 1 – Technion – IIT, Israel; 2 - Azrieli College of Engineering, Jerusalem, Israel; 3 - Georgia Institute of Technology, USA
5. **Optimization of Parameters of Internal Combustion Engine**
   A.L. Zhmudyak[1], *L.M. Zhmudyak*[2],1 -Octopol, Israel; 2 - Rehovot, 7645501, Israel
6. **Intake system for Formula SAE engine**
   Yoni Kuhr, Ilya Barbul, Technion - IIT, Israel
7. **Cooling system for Formula SAE engine**
   Lior Finkelman, Ilya Barbul, Technion - IIT, Israel
8. **Fuel system for Formula SAE engine**
   Yahav Boim, Ilya Barbul, Technion - IIT, Israel
9. **Controlled Radical Production by Non – Thermal Plasma**
   Nir Druker, Gideon Goldwine, Barry Greenberg, Eran Sher, Technion - IIT, Israel
10. **A New Modified Diesel Cycle for Small Aircraft Operating at High Altitude Conditions – A Numerical Simulation**
    Kadmiel Karsenty, Eran Sher, Technion - IIT, Israel
11. **Reforming-Controlled Compression Ignition**
    Amnon Eyal, Leonid Tartakovsky, Technion - IIT, Israel
12. **The benefits of Inverted Brayton cycle and Concept for CHP plants based on Low-Power Micro Turbine Generators**
    Boris Arav[1], *Y. Sizov*[2] 1 – TurboGEN Tech., 2 – Afeka College, Israel
13. **Particle emission characteristics of an ICE fed with hydrogen rich-reformate**
    H. Yadav, A. Thawko, M. Shapiro, and L. Tartakovsky, Technion - IIT, Israel

Organizing Committee

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- *Jacob Feldman,* Israel Aerospace Industries
- *Nir Geva,* Elbit Systems
- *Yitzhak (Itche) Hochmann,* Edmatech
- *Michael Shapiro,* Technion

Written only

The Wankel and the Promised Land - Ninety years to the Wankel Engine

Nehemia (Hemi) Oron
Elbit Systems Ltd.

In these days, when we are on the verge of technological revolutions in the automotive industry (autonomous vehicles, electrical/hybrid powered cars), it is interesting to remind ourselves of another revolution that almost occurred in the automotive industry about fifty years ago, that turned up to be a complete failure. However, this endeavor brought years later to the creation of the world's best UAV engines, till these very days. Israel's involvement in the birth, death and revival of the Wankel engine is not known to many.

The first birth of this peculiar engine occurred ninety years ago, in 1929, when Felix Wankel, a young German genius, developed in his small laboratory a revolutionary automotive engine, which was based on the same principle of the standard Otto Cycle IC fuel engine, but instead of having a piston moving forward and backwards in a cylinder, its piston was a triangular shaped section, that continuously rotates inside a housing, where each facet of it inhales, compresses, burns and exhales the fuel sprayed air. As he registered its revolutionary invention that year (as a matter of fact, the first of Wankel's patents, the 1929 one, was merely an innovation regarding the sealing concept, yet far from the infamous Wankel engine of today), he could not realize that this was going to be the beginning of a fall down of many years, until the day his rotary engine will be reborn. The following years found Felix Wankel in the Nazi Youth, thereafter in the Nazi's prison, and then at WW2 the Nazis set him free for his technical talent to be used for the war efforts. Following the war he was arrested by the Allies, until the day that some acquaintance remembered his talents and recommended he should be released and participate in the Marshall Plan to revive the German industry with his peculiar rotary engine.

This revival of the Wankel engine was far from being glorious. The rising German car makers showed some interest, but at the end of the day it was the small NSU who took on itself the challenge to develop the engine. They created a laboratory for Felix Wankel, and nominated another engineer, Walter Froede, to lead the team. Soon enough, Walter Froude and his companion Eng. Peter Paschke, developed their own version of the triangle piston engine. Wankel was disappointed, and both Wankel and Froude presented their version to the NSU management, who hardly had the budget to develop even one model of the engine. They had to make the tough decision: The Wankel model in which both the Rotor and the Rotor Housing rotated, in 3:2 speed ratio, thus creating a symmetrical balanced system (Wankel saw his dream engine as the connecting link between the piston and the turbine concepts), versus the Froede-Paschke engine, which was a practical compromise where only the Rotor was rotating in a stationary epithrochoid shaped housing. They chose the Froede-Pashke version, for its simplicity, despite Wankel's protests. History, however, continued to call the new engine 'Wankel', while Froede and Paschke were forgotten in the years to come.

The development of the new rotary engine at NSU was slow, while the automotive industry in the world blossomed in the USA, Europe and Japan, leaving the Wankel engine behind. During the sixties NSU had financial difficulties, and the Wankel Program was threatened to be shut off. The help came from an unexpected source: A small Israeli Bank, The Israel-Britain Bank, with its charismatic GM Joshua Ben-Zion, saved NSU and the Wankel engine in a brilliant financial deal. The development of the engine at NSU was resumed, with new hopes for the Wankel engine. Few years later Joshua Ben Zion played a major role in the introduction of the Wankel engine to Curtiss Wright in the USA. Some 15 years later Ben Zion was accused in Israel for a fraud in the Bank, the Bank collapsed and he was sentenced to many years in prison. A short while afterwards, apparently thanks to his friendship with PM Menachem Begin, he was released from prison because of a very poor and rapid deteriorating health. Ben Zion lived a good life for more than twenty years after his release, unlike the engine he saved.

But going back to the engine and the late sixties – the big blossom arrived. NSU's Wankel engine was great, and the growing company (now already together with Audi, later part of VW) created the unforgettable Audi NSU Ro-80 luxury car – one of the best looking cars in history – a small compact Walter Froude rotary 'Wankel' engine, enabling a large panoramic front window, in a beautifully designed car, a dream that came true. Within a few years, the revolution started: By the end of the sixties and the beginning of the seventies, the auto industries realized that the Wankel engine is the future. Dozens of Licenses from Audi NSU were sold around the globe, Wankel engine production lines emerged in all continents. Car manufacturers announced their next models will be Wankel powered. Citroen, Alpha Romeo, Rolls Royce, Ford, Mercedes, Porche, Toyota, Mazda and many others – the world talked Rotary. The big Revolution that Felix Wankel launched forty years earlier finally broke through.

And then came the second intervention, though indirectly, of the small state of Israel, in the history of the Wankel. October 1973, the Yom Kippur War. The traumatic war that surprised Israel with a coordinated attack by its Arab neighbours, ended in a painful Israeli victory, but was followed by a world petrol shortage crisis, bringing to a dramatic rise in fuel prices. The Wankel engine, remarkable in its performance and compactness, but poor in its fuel consumption, became one of the many victims of the fuel crisis. Adding the new environmental legislations promoted by the Nixon administration, which found the new born engine still immature as far as its polluted exhaust, created a death spell for the Wankel. In a matter of few years almost all the Wankel production lines around the world were closed. The world car industry, that invested billions of dollars in developing and setting new production and assembly lines, gave up the Wankel dream. The Wankel engine became a costly and painful episode in the auto industry. Some say that the late and slow introduction of new propulsion systems in the auto industry, till today, is the agonizing lesson learnt in the Wankel story.

In a small village north of Birmingham in England, some people decided it was too early to bury the Wankel engine. In the tiny plant that remained from the large Norton Motorcycle factory, a small engineering team headed by the 'British Wankel Inventor' David Garside, struggled to adapt the Wankel engine to a new powerful motorcycle. In a relatively short time, this motorcycle conquered the racing world, and was selected to be the Britain's Police motorcycle. But it was not that simple to compete with the rising Japanese motorcycle market, and in view of the difficulties of maintaining the high exhaust temperature engine in the motorcycle structure, as well as new regulations that changed the rotary engine volume calculation in the racing world - so in few years the small residual Norton plant went bankrupt, and this short revival of the Wankel engine ended.

And then came the Israelis. At the eighties Israel developed its own fighter jet, the Lavi, which was supposed to be one of the finest fighters ever created. But the program was very costly, and the Americans, who financed much of the development, and worried for their own aircraft industries, created a strong pressure on the Israeli Government to stop this program. As the Lavi program was painfully terminated in 1987 (after 102 successful flights), Israel decided to concentrate on a new rising field – unmanned air vehicles. This endeavour, born out of the tragedy of the Lavi collapse, was found to be a very smart and long vision decision. Israel became, till these very days, a major player in the UAV world market. But at that time, there were no engines in the world for such air vehicles - the smallest aircraft engines were of few hundred horse powers, the minimum power required to lift a man carrying vehicle, while the new UAV's, weighing in total less than half a ton required some 50 hp light compact engines. The first UAV's used drones models engines, or chain saw motors, which of course could not survive the demanding requirements of a military aircraft. The search of the Israelis for an engine, which became a major mission, brought them also to the small village north of Birmingham where they found David Garside and his small team, trying to survive after the collapse of their motorcycle, sharing the dream of applying their engine to UAV's. And the small Wankel engine was indeed the perfect engine for a UAV: Small, light, powerful, simple in its structure. In few years the small British Plant (later bought by Elbit Systems, of Israel), now called UEL (UAV engines ltd.), and later also the Israelis (who established the UAV engines plant in Elbit Systems), created the UAV Wankel engines, that became the leading engine models for almost all Tactical UAV's around the world for the following twenty years and more. The engine that failed to conquer the car industry conquered the UAV propulsion industry for many years.

The widespread use of the Wankel engine in the UAV market in the last twenty years, finally brought success and prosperity to this troubled engine. It is amazing to see how of all the automotive and industrial applications that this engine experienced in its ninety years, with tremendous investments worldwide, the only application that presented a return on investment, and became a success story – was the UAV application.

And so, the engine who was born in Germany before the Nazis rise, developed in Germany after the war, saved by an Israeli bank in the sixties, then was about to change the history of the car industry with huge investments in the sixties/seventies, collapsed as a result of the Yom Kippur War, was reborn thanks to few Israeli engineers who were seeking an engine to save their UAV, and became the leading UAV engine in the world for many years.

Nehemia (Hemi) Oron*, B.Sc. in Aeronautical Engineering (Technion) and MBA (TA University), was the head of Elbit Systems UAV Engine Plants in the UK and Israel for some twenty years (1998-2018). Currently a business development Senior Director in Elbit Systems, and chairman of the propulsion systems branch in the Israeli Engineers Association (AEAI).*

Oral presentations

Keynote lecture

Future engine fuels and their implications

J.B. Ghandhi*

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Keywords: Fuel; engine combustion; knock

Liquid hydrocarbons have inherently high energy density and are the fuel of choice for the transportation sector. For some select applications battery technology has advanced to a state that it is a suitable alternative. However, for the foreseeable future, the weight penalty and slow recharging rate of batteries will prevent their adoption for long-haul mobile power applications involving air- and land-based systems. The finite supply and volatile economics of fossil-derived fuels lends uncertainty to the future. Bio-derived, and perhaps renewable, fuels are an attractive alternative; their widespread use is largely limited by their economic feasibility notwithstanding other ethical issues. The use of bio-derived fuels provides either another degree of freedom or another constraint on the engine system depending on your point of view. In this presentation, some issues associated with switching to a biofuel will be discussed.

For spark-ignition engines, the autoignition of the mixture ahead of the flame front – knock – is the most critical factor that is impacted by the fuel. Other fuel properties, such as laminar flame speed and volatility, also affect the engine performance, but one can argue that they can be compensated for relatively easily. The chemical processes that lead to knock are complicated, nonlinear, and thermodynamic-path dependent. Therefore, a unique chemistry-based solution to the problem does not exist.

A detailed chemical kinetic model that uses 2027 species and 8720 reactions (Mehl *et al.*, 2011) coupled with a three-zone engine combustion model (Gilliam *et al.*, 2018) is used to demonstrate and investigate the nature of knock phenomena observed in spark-ignition engines. The model will first be used to describe a new combustion phenomena – pre-spark heat release – that can be observed under conditions relevant for highly boosted conditions. Figure 1 shows the end gas thermodynamic path for two conditions (solid and dashed red curves) superimposed on ignition delay contours for the fuel-air mixture; the ignition delay was calculated using a 50 K temperature rise threshold. The two cases were at borderline knock and had different intake temperatures. The solid curve shows a nearly horizontal portion that coincides with a chemical energy release in the negative-temperature coefficient (NTC) region of the ignition space. After this event, the end gas is in a more chemically stable state, which allows more advanced combustion phasing (and efficiency) than would be expected. The dashed curve, in contrast, sees compression heating due to a more advanced combustion phasing that avoids the NTC region.

The model will next be used to investigate the implications of fuel chemistry on engine knock phenomena in light of the potential for biofuel applications. The effects of ambient conditions including altitude will be addressed, and challenges for the future will be outlined.

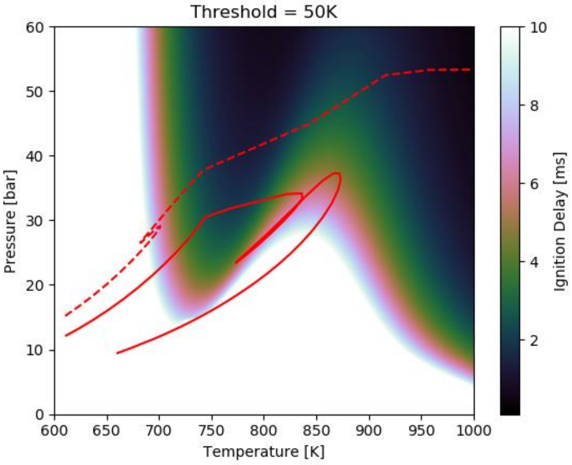

Figure 1 Comparison of end gas thermodynamic state for two operating conditions (solid and dashed) superimposed on ignition delay contour for the fuel-air mixture.

Acknowledgement

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Plenary lecture

Using advanced batteries for propulsion: scope of options

D. Aurbach

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Keywords: Li ion batteries, electro-mobility, Na ion batteries, Li-S batteries,

This talk aims at presenting most suitable options for electrochemical propulsion. We will concentrate on rechargeable batteries only, in order to be well focused. It is important to emphasize that besides rechargeable batteries, fuel cells also provide attractive solutions for electrochemical propulsion. There are also thermal, primary batteries that may be important for some propulsion missions, also beyond the scope of this presentation. Electro-mobility is the major challenge today in the field of electrochemical power sources. However, we encounter too many unsupported promises, too much noise! Examples: Many publications on 'novel' nano-materials, not suitable for practical battery applications. Nanomaterials may mean high surface area and pronounced side reactions. For instance - thousands of papers on conversion reactions anodes (nanomaterials), none of them show performance at elevated temperatures, why? Also nano-materials have puffy structure (difficult to process into electrodes). A lot of words (recently also conferences) on " beyond Li ion batteries". Beyond… for what purposes? Hard to see what can be relevant for electrochemical propulsion beyond Li ion batteries. In fact, the only relevant partner may be H_2/O_2 fuel cells, which are becoming highly relevant power sources because hydrogen can be stored in EVs at high pressure. The renaissance of Li metal based batteries is interesting, fully justified, but not for cars! Is the progress in Li-S batteries relevant to EVs? Practically, safety concerns are not being addressed well enough. Very important is to choose a-priori technologies for which the abundance of elements is secured. In this presentation we review research on advanced rechargeable batteries: Li, Na, Li-S and Li-oxygen batteries, in light of our own recent work. We provide below several selected representative references to our relevant work, published during 2018. The main theme of this presentation will be to examine what is the true horizons for all of these batteries: what we can really promise. For Li ion batteries the frontier includes Ni rich, Mn&Li rich $Li_x[NiMnCo]O_2$ cathodes and C-Si anodes. The anode side: intercalation, alloying or conversion reactions will be discussed as well. We will discuss Li metal as an anode material in high energy density rechargeable batteries. The stability of high specific capacity cathodes and anodes during prolonged cycling is a big challenge. Means for mitigating capacity fading mechanisms will be suggested. R&D of novel battery systems requires to invest great efforts in basic science, in order to understand the correlation among structure, morphology, surface chemistry and electrochemical performance of all the components in the power sources and storage devices. Electrochemistry, spectroscopy, diffractometry, high resolution microscopy and calorimetry should be employed simultaneously in each single study. Today we are experiencing the nano revolution. However, the relevance of many nano-materials to the field of high energy density batteries is very questionable. While nano-materials have advantages from kinetics point of view, for high energy density batteries they may mean pronounced side reactions and low volumetric specific capacity. The status of several "beyond Li battery" technologies and their relevance for propulsion will be discussed. Na ion batteries struggle with intrinsic structural stability problems. A nice progress was made with Li-S cathodes. The Li anodes is the limiting factor. Regarding Li-oxygen batteries, a key problem is the high reactivity of ALL relevant electrolyte solutions to the peroxide/superoxide moieties formed by oxygen reduction. It is important to emphasize that demands for propulsion are not related to electro-mobility and EVs only. There are other needs such as drones, unmanned airplanes and vehicles, robots, for which energy density may be the most important need, on the account of cycle-life and durability. For such needs, Li-S and other Li metal based batteries may be important. In summary, the presentation intends to provide an integral view on true horizons of several important battery systems, in light of intensive, long term work at BIU.

Acknowledgement

Our work is being carried out in collaboration with BSAF Germany and General Motors USA. It is also part of our efforts in the framework of INREP – Israel National Research centre for Electrochemical Propulsion, supported by the Israel Committee of High Education and the Israeli Prime Minister office.

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Plenary lecture

Research Activities, Challenges, and Future Directions in UAV Propulsion

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Keywords: Engine; Propeller; Materials; Efficiency; Modelling

In this lecture, an overview of current and future research activities and challenges for UAV propulsion systems will be reviewed. This presentation will emphasize US-based studies centered on combustion engines and hybrid configurations for future airborne package delivery and surveillance applications. This presentation will discuss 3 paths to efficiency improvement: 1) improving fuel/air combustion, 2) reducing engine mass, and 3) reducing drag on small propellers. For internal combustion engines, it is well known that efficiency decreases with decreasing cylinder size due to the relative increase in surface area per unit volume. The high rates of heat transfer through cylinder walls reduces the available heat for combustion leading to incomplete combustion of the fuel. Heat retention is critical and can be achieved through use of thermal barrier materials and optimally designed combustion chambers. An overview of recent activities to incorporate thermal barrier materials (titanium and silicon nitride) on small 2- and 4-stroke UAV engines will be discussed. In both studies, the engines were able to operate effectively, even though combustion was not optimized. For example, by replacing aluminum with titanium as the head material in a 2-stroke engine, the efficiency was slightly improved at reduced speeds as shown in Figure 1.

This presentation will also discuss the issues and inefficiencies accompanying micro-propellers used to power small and medium-sized UAVs. Micro-propeller design and performance is often not considered, even though the efficiency losses associated with propeller operation are significant. Propellers used to power manned aircraft operate under turbulent conditions because their size (diameter) enables the blade surfaces to experience high Reynolds numbers (>50,000). In contrast, the small prop sizes used in small UAVs force them to operate in the less-efficient laminar regime (Reynolds numbers< 50,000). Laminar operation advances air separation at the leading edge of the blade which subsequently increases the relative size of vortices, which impart drag. Significant performance and efficiency benefits can be achieved by overcoming the inherent efficiency losses emanating from small-sized propellers. The noise generated from micro-propellers corresponds to the inefficiencies, so any modification that improves efficiency Attempts at improving propeller efficiency have primarily focused on engineering surface features and blade geometries. These approaches have not yielded significant gains and a completely radical approach to blade design needs to be undertaken. One novel concept that will be presented is the incorporation of channeling to direct air flow from the high-pressure side of the blade to the low-pressure side to minimize vortex formation. Initial modelling efforts (Figure 2) using computational fluid dynamic suggest that incorporation of one or more channels can reduce drag without any significant loss of lift. The location and size of these channels is critical to minimize affecting lift. Further research in this area is proposed.

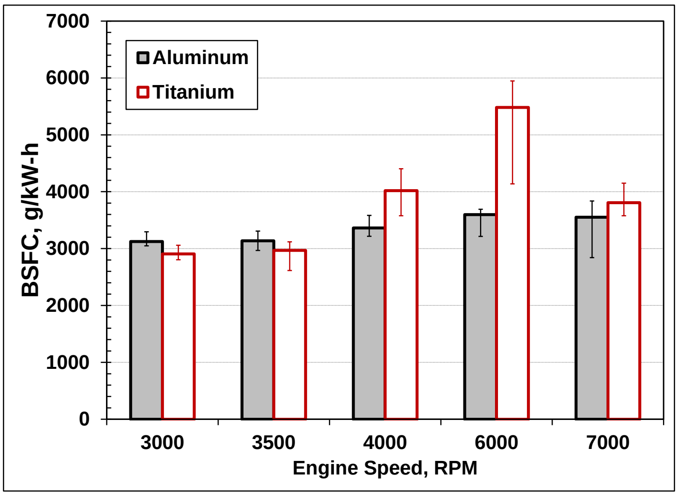

Figure 1. Brake specific fuel consumption results associated with maximum torque for each operating point between 3000 and 7000RPM.

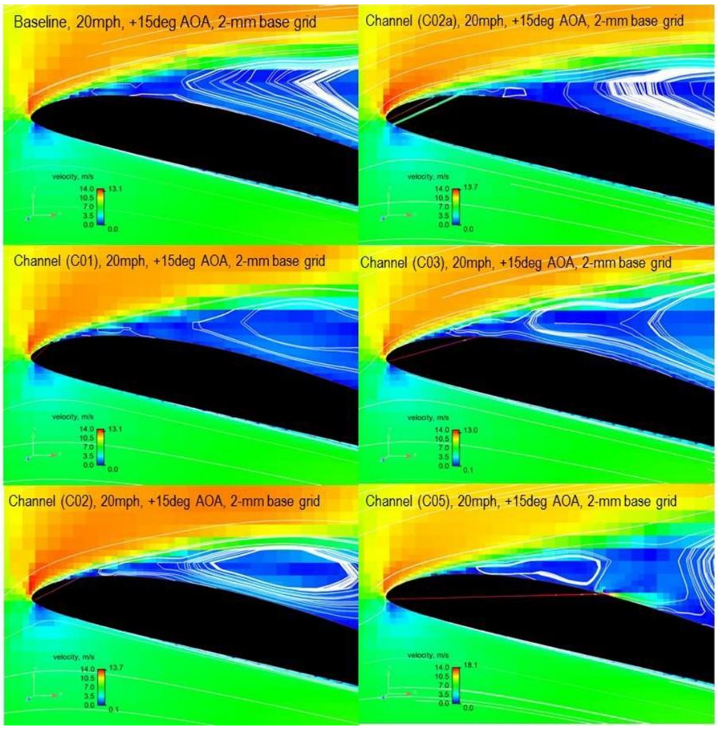

Figure 2. Preliminary CFD modelling indicates that drag may be reduced by placing small channels near the leading edge from the high-pressure to the low-pressure side of the blade.

Acknowledgement

This work was supported by sponsored by the Laboratory Directed Research and Development Program of Oak Ridge National Laboratory, managed by UT-Battelle, LLC, for the U. S. Department of Energy.

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Plenary lecture

Guide to design of efficient UAV propulsion

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Keywords: Engine; Energy consumption;

The lecture will cover the options that we may have in the design of various power plants that drive propellers of UAVs.

The main issue is to assure that all the components should operate at their maximum efficiency, and minimal weight to assure the longest flight for a given mission

Different practical energy sources will be compared a as well as the energy conversion devices into mechanical power such as ICE, Fuel Cells with Electrical motors etc.

The advantages and shortcoming of most common system is described with a glimpse for the future

To summarize - there is no one system suitable for all the application - very encouraging fact that will assure employment of good engineers in UAV Industry

I hope that this lecture may help you to make the right decision

Plenary lecture

UAV engines to benefit from direct injection, jet ignition and precise oiling

Albert Boretti, Independent Scientist, Australia

Direct injection coupled to some sort of jet ignition is now popular in electrically assisted, turbocharged, F1 engines because of the pressure to reduce fuel consumption. Operation lean of stoichiometry stratified with about λ=1.5 permits fuel conversion efficiencies of about 45% at peak power. The lean stratified mixture by late direct injection is less prone to knock than a homogeneous, stoichiometric mixture, because of fuel vaporization and because of the limited time to develop knock. The availability of jet ignition further improves the resistance to knock, as combustion starts almost simultaneously across the chamber with many high energy ignition points and progress at much higher speed. Compression ratio may drastically increase. Combustion of a lean stratified mixture at the center of the chamber also occurs with reduced heat losses. Potentially much larger gains are expected if applied to two stroke, rather than four stroke engines, otherwise much less fuel efficient and more polluting than their four stroke counterparts. When reference is made to the still very basic design of the late 1990s, when fuel and oil were premixed in the intake of the engine, the opportunity to use direct injection has been marginally explored, mostly in the form of low pressure, air assisted injectors of slow actuation, plus some sort of precise oiling. The two stroke engines suffer of the exhaust ports closing after the intake ports. Precise oiling, with separate injection of oil where needed, allows directly injecting only fuel in the combustion chamber. By using high pressure, high flow rate, high atomization, fast actuation direct injectors, the fuel mixture can be produced when the ports are all closed, thus preventing any fuel from escaping the combustion event. Then, by high energy bulk ignition by jets of the lean stratified mixture, a fast and more complete combustion of the in-cylinder mixture occurs and completes before the exhaust ports open. Further developments of two stroke engines, featuring direct injection and jet ignition plus precise oiling is thus recommended to improve power density while also improve fuel economy and eventually reducing emissions. These novel two stroke engines are expected to deliver same fuel economy and emissions of present four stroke engines, but within the much simpler, less expensive, reduced weight, improved packaging, and finally much larger power density of the two strokes.

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In-Cylinder Steam Reforming in UAV Diesel Engines

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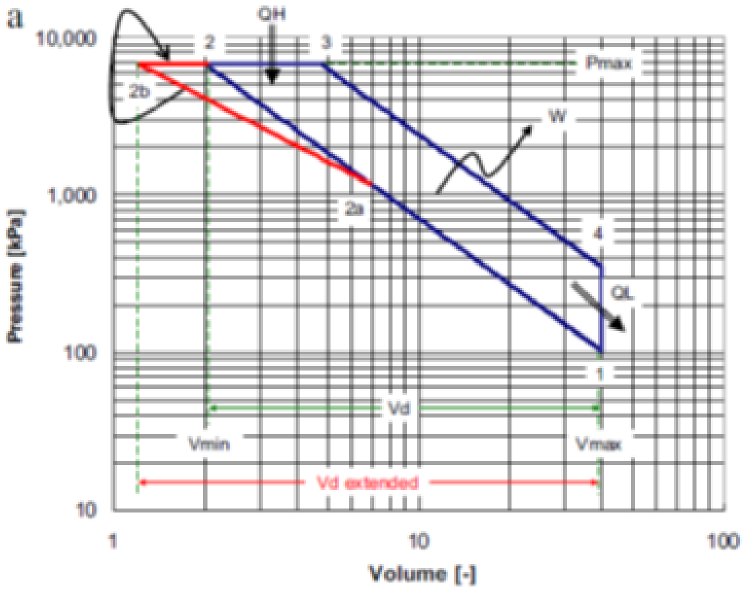
Keywords: UAV engines, Diesel Cycle, In-Cylinder Steam Reforming

Starting from the baseline of a Diesel engine, we show that with a suitable in-cylinder catalytic coating and well controlled injection of a reforming-mixture during a certain period in the compression stage, a significant increase in the ideal cycle efficiency is achievable (from 67% to 78% for an initial compression ratio of 25). In such an arrangement, the fuel injection session comprises a two-stage process. In the first stage, the reforming-mixture is injected into the hot previously compressed cylinder charge over the catalyst. Residual heat is absorbed in the endothermic steam reforming process to produce hydrogen and carbon monoxide. The heat absorption cools the compressed mixture and enables a higher compression ratio up to the maximum allowed pressure, while the temperature of the cylinder charge remains constant. In the second stage, only fuel is injected to initiate combustion while the absorbed heat (of the first stage) is released through the complete oxidation of the additional hydrogen and CO. Essentially, the absorbed heat is exploited to produce in-cylinder hydrogen, which increases the cycle efficiency.



The pressure-volume diagram of the modified Diesel cycle

Preliminary comparative tests with a real diesel engine have shown promising results. In these tests, we measured the pressure diagram in the commercial engine and in the modified one, and analyzed the diagrams to yield the instantaneous rate of heat absorption and release during the cycle. Also were measured, the engine power and its fuel consumption that showed a power increase of around 10% and a corresponding decrease in the specific fuel consumption of about 8%.

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Laser Energy Transfer – Preliminary Experimental Results

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Keywords: Energy transfer, wireless charging

Electrical aviation is a new and emerging technological market. The electrical propulsion provides many advantages to the air vehicle. For example, it enables the use of distributed propulsion, increases takeoff and climb performance, reduces maintenance costs etc.

The shortage of electrical propulsion is the low specific energy of current electrical energy sources. The most common energy source used today is battery. Today's electrical airplanes flight time is limited to about 1-2 hours. This is true that for general aviation this flight time is sufficient in most cases. However, for commercial or military airplanes this is a significant drawback.

One of the ways to increase the flight time is to remotely transfer energy to the airplane. Several technologies were widely researched to transfer energy to remote location including microwave of laser power beaming.

IAI energy sources team performed a theoretical and experimental study to show the feasibility of wireless energy transfer to airplanes.

The small scale experiment, transferring power to a 300m distance performed at IAI, shows above 20% conversion efficiency at significant power levels.

Acknowledgement
This work was supported by the Israel MOD.

High-pressure thermochemical recuperation of exhaust gas energy in internal combustion engines

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Keywords: Waste heat recovery; Thermo-chemical recuperation; Steam reforming of methanol; High-pressure reforming; Direct injection

This research describes the development of a high efficiency low pollutant emission propulsion system that is based on methanol as a primary fuel. Methanol is a low carbon intensity liquid fuel that can be produced from renewable and non-renewable sources and can be reformed to produce high hydrogen-content gas called reformate. The latter approach is called thermochemical recuperation of engine waste heat. It allows engine efficiency increase together with pollutant emissions reduction.

In an internal combustion engine about 30% of the fuel energy is being wasted with the exhaust gas. In the approach we developed, this energy is used to sustain endothermic fuel reactions of methanol reforming to high hydrogen-content reformate. Thus, the lower heating value of the fuel is increased and the combustion properties of the fuel are improved. That is because hydrogen has excellent combustion properties such as high laminar flame speed and wide flammability limits.

Methanol reforming is not a new concept and was widely investigated in the 1980's. In the previously published studies, the reformate was fumigated through the intake manifold, leading to uncontrolled combustion and reduced maximal power due to reduction in the engine volumetric efficiency. Tartakovsky *et al.* (2011, 2013), offered to solve these problems by injecting the reformate directly into the cylinder. This thesis describes the development of the proposed approach from the idea stage up to the working prototype.

A joint model of the engine and reformer was developed and applied in simulation software. The simulations showed the system is feasible, the reforming system size is reasonable and the reforming system improves the engine efficiency. The energy required for reformate compression was calculated. We found that if reforming is carried out at atmospheric pressure, the compressor power consumption makes the concept unfeasible. We offered to compress the primary liquid fuel instead of compressing the gaseous reformate, and thus reduce the compression power consumption by several orders of magnitude. This led to the introduction of a new concept that we call "High-Pressure Thermochemical Recuperation". By using the developed simulation tool, the new concept was investigated and found to improve significantly the overall engine efficiency. This laid the theoretical basis for the experimental part of the research.

Since the engine reformer system is complex and there was no available gaseous fuel direct injection engine, there was a need to develop both an engine and a reforming system. First, an engine was developed and fueled with reforming products from compressed gas cylinders. The reforming products fed engine efficiency was improved by 18-39% compared to gasoline, and its CO, HC and NOx emissions were reduced by 90-96%, 85-97%, 73-94%.

At the last stage of the research, a reforming system was added to the engine and the creation of the High-Pressure Thermochemical Recuperation system prototype was completed. The system improved the engine's efficiency by 19%-30% and reduced its CO2, HC, CO and NOx emissions by up to 15%, 96%, 91% and 97% respectively. Hence, the proposed concept of High-Pressure Thermochemical Recuperation shows excellent potential for future development.

Acknowledgement

This work was supported by the Grand Technion Energy Program, Israeli Ministry of Science, Space and Technology, Dr. George Elbaum, Irwin and Joan Jacobs and the Rieger Foundation.

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The Elbit Systems 903 Next Generation Rotary Engine: From Simulation to Prototype

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Keywords: UAV; Wankel; Rotary; Prototype; Testing

The 903 next generation rotary engine is currently being developed at Elbit Systems as a means of advancing rotary propulsion system technology. The design incorporates a “hybrid” engine bearing system with both hydro-dynamic and roller bearings, allowing for a closed-loop oil system and improved engine core reliability, while maintaining the Air Cooled Rotor (ACR) Wankel’s superior power-to weight ratio and compact installation size over the Oil Cooled Rotor (OCR) Wamkel design.

The 903 engine was designed with the aid of various calculation and simulation tools including a one-dimensional flow internal combustion engine simulation model and CFD for optimization of cooling system design.

Novel production methods were incorporated into the prototype’s design, with the entire engine rotor produced using 3D printing- something unheard of in production rotary engines.

First announced at the 2012 PTUAV, the 903 has come to fruition this year with the successful production, assembly, and testing of prototype number one. The assembled prototype was first tested on a motoring test bench to confirm adequate oil pressure and combustion chamber sealing. A short idle and low-load test followed with satisfactory results confirmed by partial disassembly and engine core evaluation. The engine ECU maps adapted directly from the current 902 production engine were then improved to allow best performance with the appropriate flight propeller. Finally, a 3 hour standard running in procedure was attempted, cut short by the failure of a dynamic oil seal in the high-pressure shaft oil supply chamber. The Prototype engine was run for a total of 7 hours, and important lessons were learned towards the continuation of development and testing.

Development of the 903 engine opens up further possibilities such as engines with a higher life span multi-rotors and more power (due to improved cooling and bearing lubrication). These are not limited to the UAV market, with mobile generators and electric car range-extenders among possible future implementations.

Performance comparison of a direct-injection ICE in diesel and spark-ignition operation with methanol reforming products

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Keywords: Hydrogen-rich Port-Injection; Hydrogen-rich Direct-Injection; Methanol-Steam-Reforming; Thermo-Chemical Recuperation

Waste heat of an internal combustion engine can be partially recovered using the energy of the exhaust gases, to promote endothermic reactions of fuel reforming in a process called Thermo-Chemical Recuperation (TCR) [1], and presented in figure 1. Alcohols like methanol as primary liquid fuels, can be reformed at relatively low temperature to produce multicomponent gaseous fuels with higher heating value following equation 1. The obtained experimental results from low compression ratio engine [2] showed that engine energy efficiency is improved by 18%-39% (higher values at lower loads) and pollutant emissions are reduced by 73-94%, 90-96%, 85-97%, 10-25% for NOx, CO, HC and CO2 emissions, respectively, compared with gasoline in a wide power range.

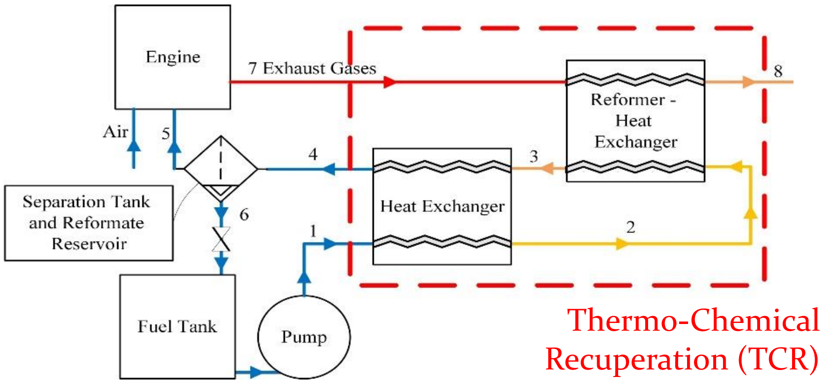

Figure 1. Schematic of the high pressure TCR system.

(1) Methanol Steam Reforming (MSR)

$$CH_3OH + H_2O \rightarrow 3H_2 + CO_2 \qquad \Delta H \approx 50 \text{ kJ/mol}$$

We go beyond the previous study by implementing the MSR fuel in a high compression ratio research-engine. The baseline research engine works in a Diesel cycle; however, the engine has been adjusted to operate also in Otto cycle. In the current study, the engine fed by MSR in direct and port injection methods.

The engine performance of both gas fuel injection methods were investigated and compared to diesel fuel injection. Notably, the engine efficiency of an Otto cycle is higher than Diesel cycle for the same compression ratio engine. The engine efficiency for MSR port injection was the highest for the entire possible load range. Conversely, the engine efficiency with direct MSR injection was higher than diesel injection for low engine loads; but, along with raise in load, the trend has been changed and the engine efficiency for MSR direct injection was lower than diesel fuelled engine. The reason is related to late MSR injection and poor mixing toward the end of the compression stroke [3].

Acknowledgement

This work is supported by Nancy and Stephen Grand Technion Energy Program (GTEP) and the Council for Higher Education (CHE)- Planning and Budgeting Committee (PBC)

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Mechanism of rotational speed control at operation speed limits for propellers with constant pitch

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Introduction

A simple way to approach RPM limiting in an engine with constant pitch propeller is proposed.
The method allows safe RPM limiting while maintaining optimal AFR at normal operation. It enables also to overcome a sudden load change while remaining in a desired engine speed range.
Maintaining the engine speed at a desired range is important for the integrity, performance and life expectancy of internal combustion engine. A UAV engine with constant pitch propeller can be affected by sudden load change due to electrical power consumption changes and wind gusts during flight, thus directly affecting the UAV flight performance. By controlling the electronic throttle map over speed limiting can be achieved while maintaining an optimal air fuel ratio, and also a load surge resistance while reducing pollution.

Rpm limiters

During UAV ascent, an engine with a constant pitch propeller will run at max speed, in that case a wind gust can cause over speed and damage to the engine. Old internal combustion engines used mechanical RPM governor system to make sure the engine speed remain in a safe zone, those governors used mostly a centrifugal force with weights to force ignition cut or fuel reduction or air reduction to the combustion chamber, that created unsafe working regime for the engine and plane or greater pollution at suboptimal air fuel ratio. New engines uses the same basic principle of ignition cut, air or fuel reduction at RPM limiting therefor not working at optimal ratio.

Load surge

During UAV decent, an engine with a constant pitch propeller will run at minimum speed, in that case a load surge can cause under speed for alternator thus cutting power to critical systems or an engine cut and a risk to the UAV.

Throttle control map

In order to overcome the under and over speed scenarios a simple throttle control map was created at ADS propulsion division. This map converts the UAV control system command for the propulsion system into a command for the electronic throttle, at accepted operating speeds the map does not change the control system command, when reaching the limits this command is reduced or increased to keep engine speed at the desired range. The ECU controls the amount of fuel injected according to the throttle, RPM and other signals to keep an optimal mixture at all time for maximum performance, low pollution, safer operation and smother operation.
A simplified map shows the conversion between the UAV control systems to the throttle control.

	Engine speed		
UAV control command [%]	Approaching under speed	Normal high	Approaching over speed
0	20	0	0
50	70	50	30
100	100	100	60
	Throttle command [%]		

Fuel Cells Technology for UAVs

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Keywords: Fuel Cell, UAV, Hydrogen

The overall UAV market is huge, with some pegging the opportunity at $91 billion over the next decade. The military represents the majority of the market, but non-military verticals are increasingly implementing UAVs for applications such as crop spraying, video filming, surveying, and package deliveries. At the present, the drone market is restricted to applications with extremely limited flight times. Introduction of disruptive technology enabling significantly long flight time will lead to increase in the market for drones and can be potentially highly profitable to the technology pioneer.

Such a technology will need to rely on quite electrical engines operated with high power density energy devices. Due to the known limitations of current battery technology, fuel cells have been receiving significant attention in recent years. In theory, the energy density in a fuel cell operated device is an order of magnitude higher than the best available battery today (Fig. 1). By definition, fuel cell converts chemical energy directly to electromotive energy without going through a combustion cycle, making it much more efficient than any know internal combustion engine. Fuel cells will continue to generate power as long as they are supplied with fuel much like combustion engines and can be fuelled easily and quickly as well.

In this talk, I will give an overview of the state of fuel cells technology today, and their implementation in the global effort to shift away from the use of fossil fuels, in what is commonly known today as the Hydrogen Economy.

The use of hydrogen and fuel cells is increasing rapidly, and motivates both research institutes and industry to make large investment in the development of efficient, durable, light and cost-effective fuel cells. The technology has reached a maturity to penetrate the aviation industry, and raises lots of hopes among all players involved. I will focus in this talk on the UAV industry, through demonstration of one of the most efficient and sophisticated fuel cell operated drones today.

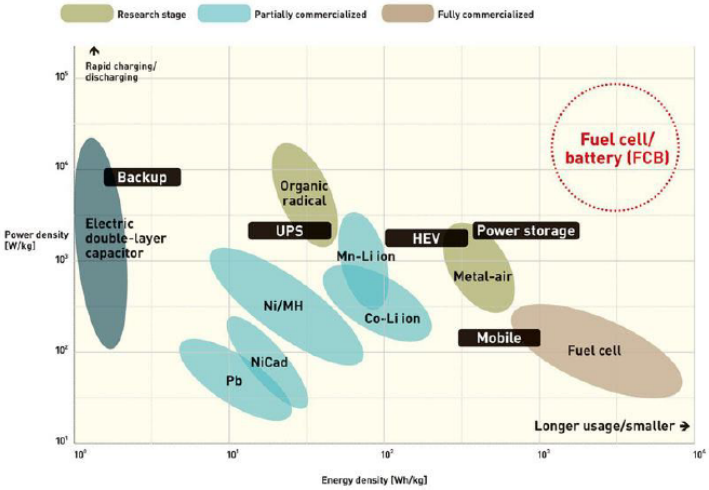

Figure 1: Ragone plot comparing the performance of various batteries (energy density vs. output density) © Atsushi Tatsumi

CFD Simulation of Ethanol Steam Reforming for Stirling Engine

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Keywords: Stirling Engine; Ethanol burner, CFD, Ethanol Steam Reforming; Multiphysics Simulation;

1. Introduction

External combustion engines, like the Stirling engine, have benefits over their internal combustion counterparts due to their ability to remain completely sealed from the elements and their nearly silent operation. Stirling engines are inherently robust, quiet, and only require an external heat source for operation. These characteristics make these engines ideal candidates for military and commercial applications where clean, quiet power is desired [1]. Figure 1 shows photos of Stiriling Engines burners.

Figure 1. Stirling Burners [1].

The demand for hydrogen has increased recently due to progress in fuel cell technologies. Fuel cells are electrochemical devices described as continuously operating batteries and are considered as a additional clean source of electric energy for UAV, containing high energy efficiency, and its resulting emission is just water [2]. Hydrogen can be produced by steam reforming of Ethanol. The use of ethanol presents several advantages, because it is a renewable feedstock, easy to transport, biodegradable, has low toxicity, contains high hydrogen content, and easy to store and handle. Ethanol Steam Reforming (ESR) occurs at relatively lower temperatures, compared with other hydrocarbon fuels, and has been widely studied due to the high yield provided for the formation of hydrogen. A new computational fluid dynamics (CFD) simulation model of the ethanol steam reforming (ESR) has been developed in this work. The reforming system model is composed from an ethanol burner and a catalytic bed reactor. The liquid ethanol is burned inside the burner. The radiative heat flux from burner is transferred to the catalytic bed reactor for transforming the ethanol steam mixture to hydrogen and carbon dioxide (see Figure 2).

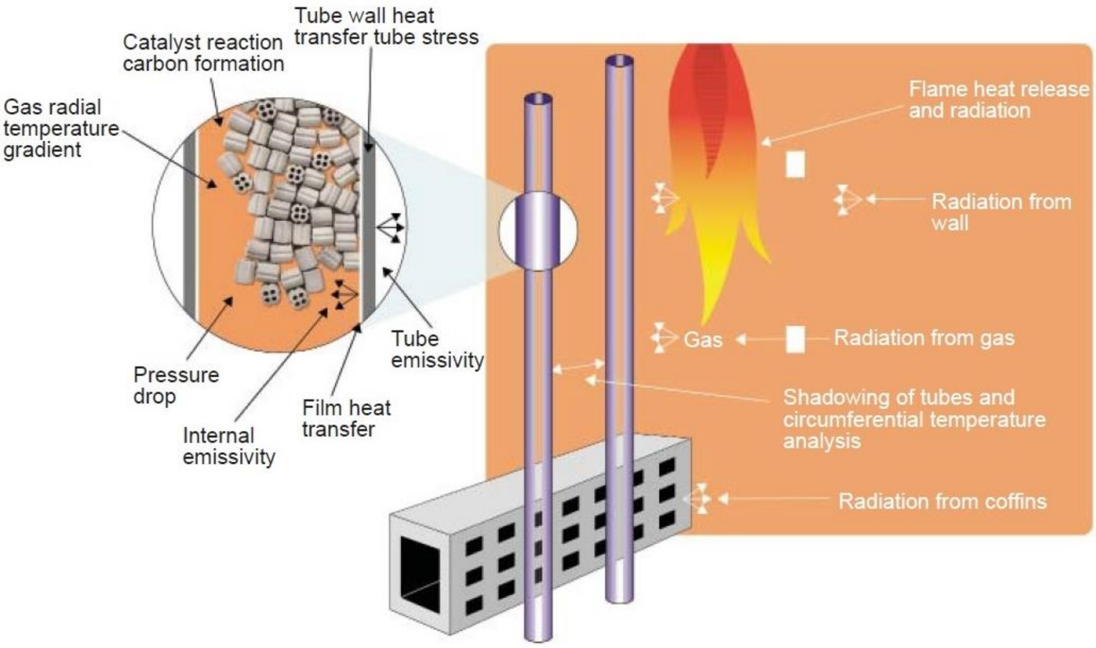

Figure 2. Heat transfer mechanisms in steam reformer [3].

The proposed computational model is composed of two phases—Simulation of ethanol burner by using Fire Dynamics Simulator software (FDS) version 5.0 and a multi-physics simulation of the steam reforming process occurring inside the reformer. COMSOL multi-physics software version 4.3b has been applied in this work. It solves simultaneously the fluid flow, heat transfer, diffusion with chemical reaction kinetics equations, and structural analysis.

2. Main Findings of the works

Figure 3 shows the 3D temperature field inside the reformer.

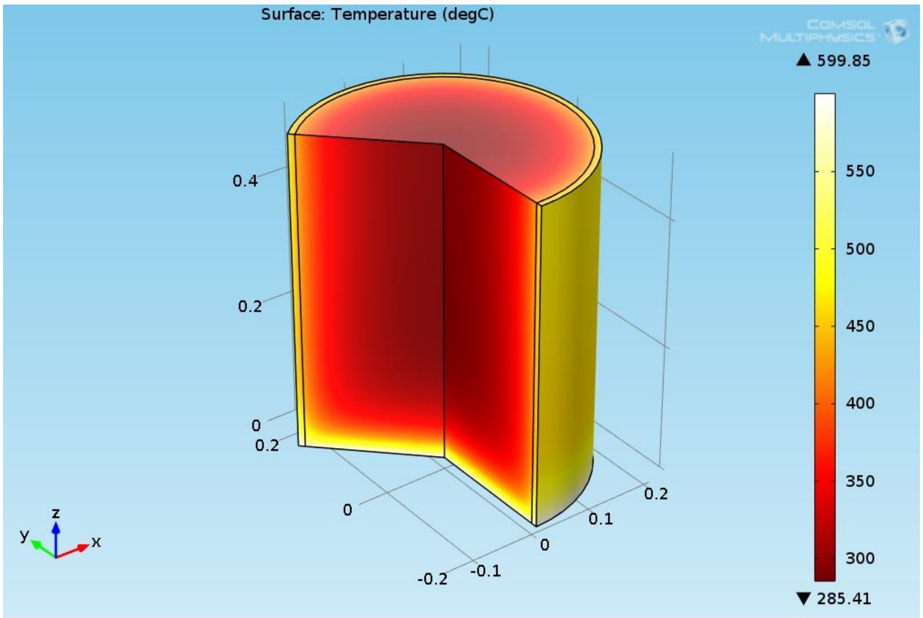

Figure 3. 3D plot of the reformer temperature field.

As can be seen from Figure 3, the temperature at the bottom section of reformer is lower than the temperature at the upper side. The temperature of the steel is much higher than the temperature of the catalyst. This is because of two reasons: Firstly, the endothermic reactions absorb the heat, and secondly, the catalyst is much thicker than the steel tube.It is shown that the heat release rate produced by the ethanol burner, can provide the necessary heat flux required for maintaining the reforming process. It has been found out that the mass fractions of the hydrogen and carbon dioxide mass fraction are increased along the reformer axis. The hydrogen mass fraction increases with enhancing the radiation heat flux. Figure 4 shows the mass fractions of the species (ethanol, CO_2 and H_2O) along the reformer axis for inlet temperature of 600 °C.

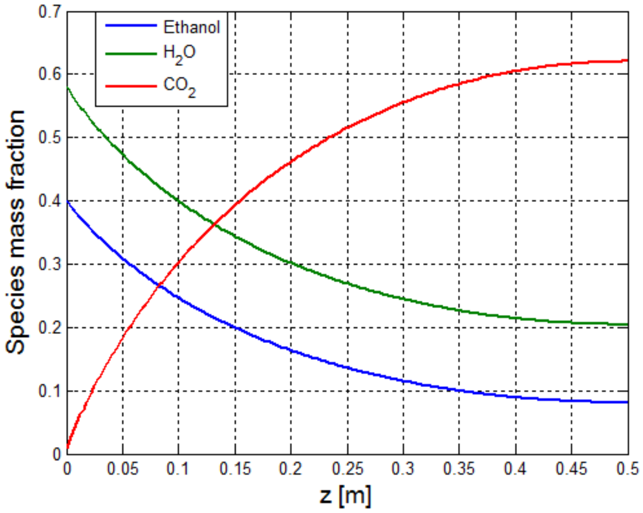

Figure 4. Mass fractions of the species (ethanol, CO_2 and H_2O) along the reformer axis.

The mass fractions of the ethanol and steam decay along the reformer axis. The ethanol conversion is 80.3%. The ethanol and the steam decays at the same slope. Similar values have been reported in Reference [4]. Figure 5 shows the mass fractions of hydrogen along the reformer axis.

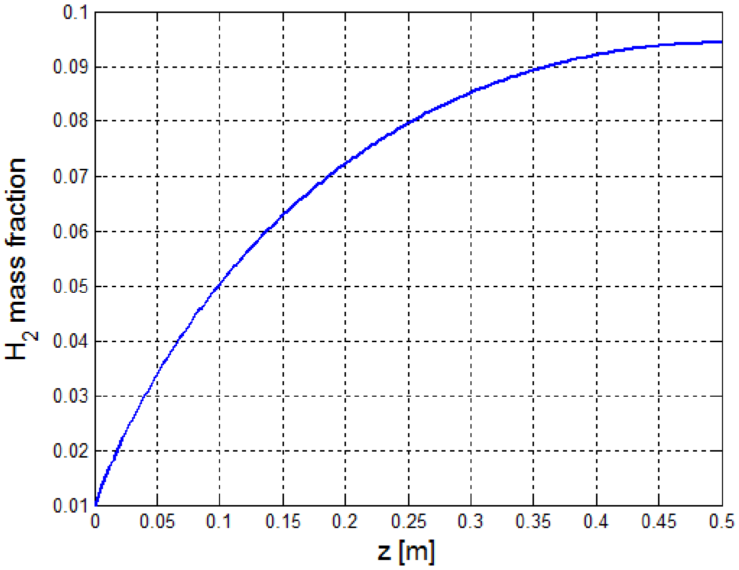

Figure 5. Mass fractions of the H_2 along reformer axis.

This figure clearly shows a considerable increasing of hydrogen mass fraction along the reformer axis. The increase in Hydrogen mass fraction is 89.4%. The sum of hydrogen, ethanol, carbon dioxide, and steam mass fraction at the reformer output is 1 as expected according the mass conservation law.

It was shown that Von Mises stresses increases with heat fluxes. Safety issues concerning the structural integrity of the steel tubes are also addressed. Steel tube rupture and cracks may cause release of the hydrogen gas to the reformer facility. Hydrogen has wide flammability limits and very low ignition energy [5]. Therefore, hydrogen present safety concerns at limited ventilation conditions because of the danger of explosive mixture formation that may cause severe damage [6–8]. This work clearly shows that by using ethanol which has low temperature conversion, the decrease in structural strength of the steel tube is low. The numerical results clearly indicate that under normal conditions of the ethanol reforming (The temperature of the steel is about 600 °C or 1112 °F), the rupture time of the HK-40 steel alloy increases considerably. Figure 6 shows the effect of temperature stress rupture of HK 40-2 steel alloy [9].

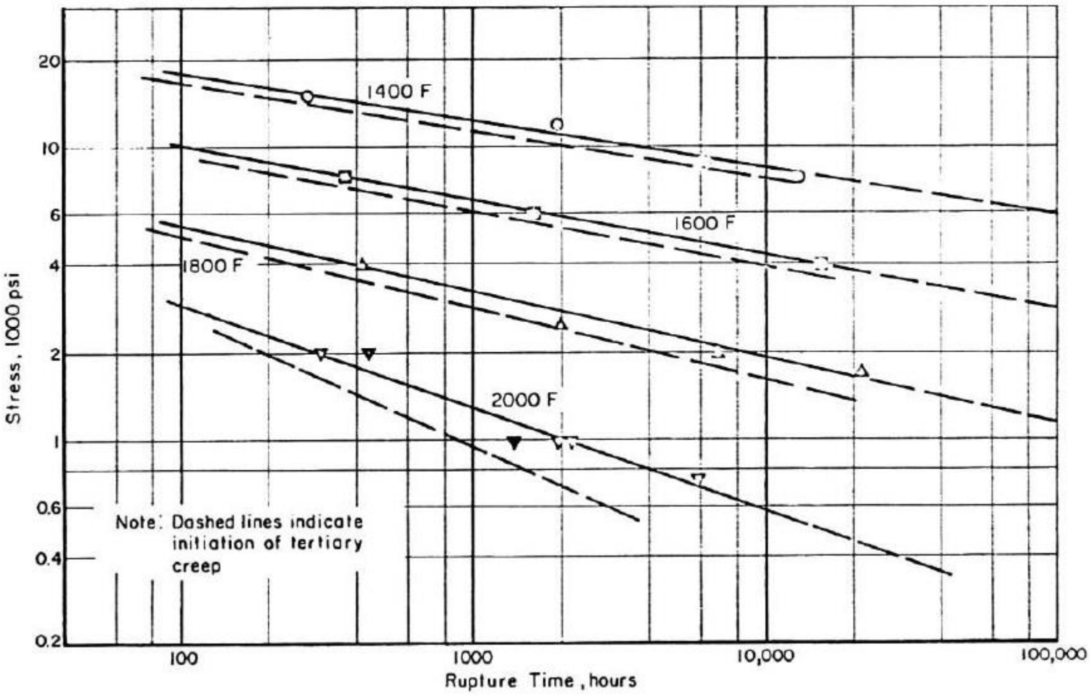

Figure 6. The effects of the temperature on the rupture time of HK 40-2 alloy [9].

Figure 6 clearly indicates that under normal conditions of the ethanol reforming (the temperature of the steel tube is about 600 °C or 1112 °F), the rupture time increases considerably. For this case the rupture time is greater than 100,000 h (more than 11.4 years).

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Maintenance of electric propulsion systems

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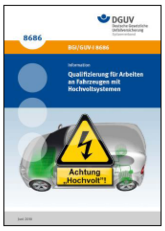
Keywords: Carbon fluoride; manganese dioxide; hybrid; lithium; primary

Qualification for works on vehicles with high voltage systems


DGUV
8686
BG/GUV-I 8686
Qualifizierung für Arbeiten an Fahrzeugen mit Hochvoltsystemen
Achtung „Hochvolt“!

Level 3 HVE woep | **for example**

Working on energized HV systems and working on close-to-touch and energized parts

- Troubleshooting
- Changing components under voltage

Level 2b HVE for works on non-intrinsically safe HV systems

Level 2 HVT | **for example**

Establish voltage-free status Electro-technical Working under voltage-free condition

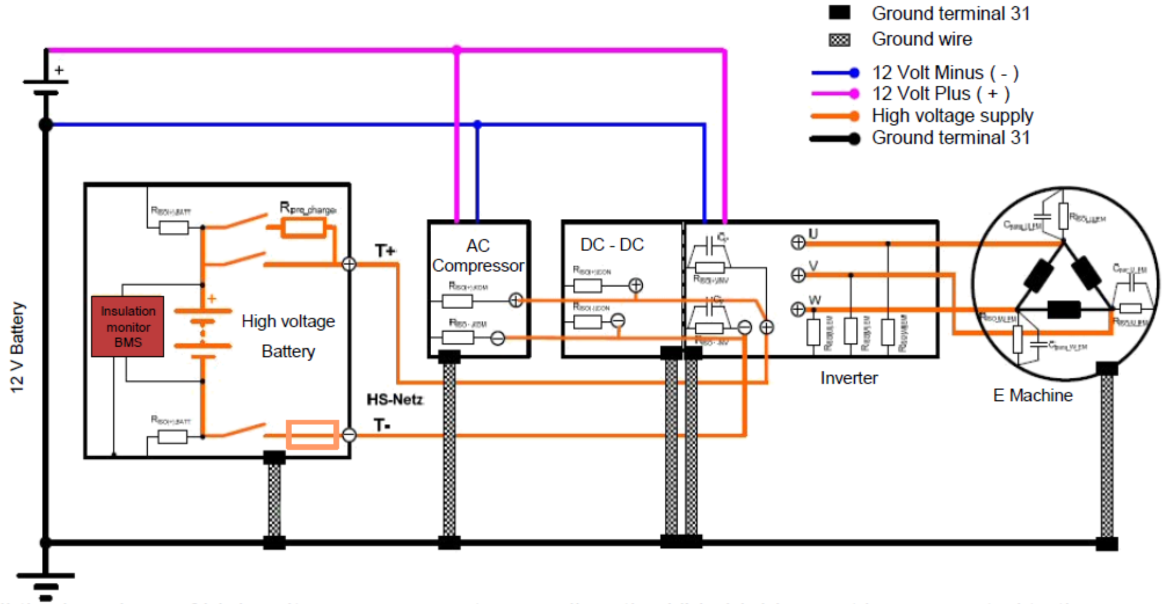
- Disconnect
- Securing against re-closure
- Determining voltage-free status
- Replacement of HV components
- Pull out plug + parts replacement (e.g. DC/DC converter, electrical air conditioner)

Level 1 EIP | **for example**

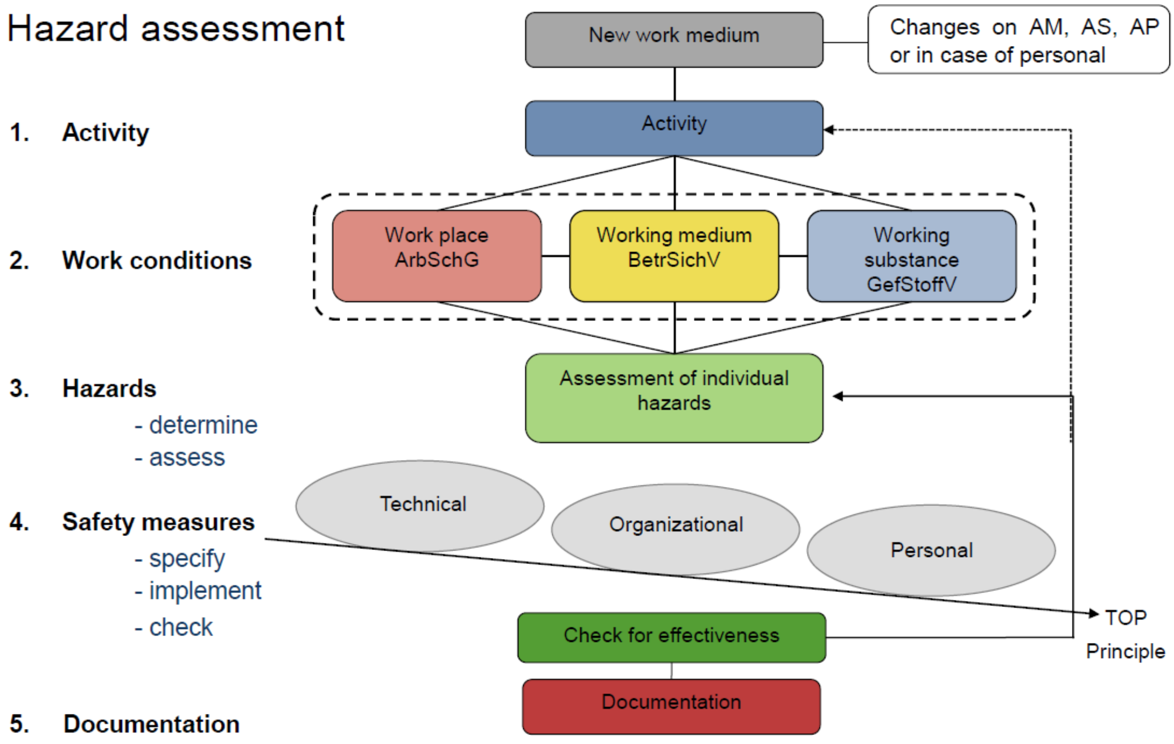
Non-electro-technical works

- Vehicle care,
- Body works,
- Oil change, tire change

Technical safety measures - Insulation monitoring



All the housings of high voltage components as well as the HV-shields must be connected to the ground (terminal 31). Only if the same ground potential is present everywhere and if there is no potential offset between the high voltage components, then the insulation monitoring system will be able to function correctly and to detect the leakage currents from the low voltage to the high voltage on-board network. If an insulation fault is detected, the cut-off relay will open immediately.



Hazard assessment

1. **Activity**
2. **Work conditions**
3. **Hazards**
   - determine
   - assess
4. **Safety measures**
   - specify
   - implement
   - check
5. **Documentation**

Execution of works in the presence of voltage

Prior to the start of planned works the person responsible of the works has to coordinate and agree on the **type, place, time and possible consequences** to the system with the person responsible for the system. This agreement can either be verbal or in case of complex systems be written as determined by the work instructions. Subsequently the person responsible for the system issues **the permit for execution of the work foreseen**.

The person responsible for the work must **prior to the start** of the planned works **assess** the **condition of the system and the ambient conditions**, e.g. space constrictions, rain, thunderstorm etc. at the work place. If he/she is convinced that the planned works can be **safely executed** and the **requirements of the work instructions are fulfilled**, then he/she may issue the release for the execution of the works as per earlier instructions given to the persons participating.

The person executing the work is under obligation to **carry out** the works as the **work instructions**. If he/she is either **unable to execute the works safely** or **to guarantee them any longer**, then**the works are to be terminated**. In such a case, the person responsible for the work must be informed about the work termination.

Propulsion System Availability Improvement by Advanced Health Monitoring techniques

How to use the data collected from the Engine's sub-systems and additional sensors to increase availability and avoid unnecessary over-maintenance.
Including the use of exact monitoring of systems Frequencies and Artificial Intelligence.
A proactive approach to provide the engine with the necessary maintenance exactly when the engine needs it.

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Introduction

Today UAV's internal combustion engines maintenance method is based on engine working hours. It means that there is no difference between UAV's engines which are working in a different environment and different engine loads. The only parameter that determines whether to inspect or replace components is the engine's accumulated working hours. This approach leads to over-maintenance and avoid the ability to predict fracture faults, reduce pollutant emissions and increase time between maintenance rounds, thereby saving money and spare parts.

Most of the UAV has a typical profile mission which include take-off (usually in high RPM), cruising and landing. But these profiles are different from each other by the cruising height, environmental condition, platform weight, etc. So, how come that they all need maintenance at the same time?

Modern UAV's engines are equipped with an ECU that is capable of monitoring and maintaining various sensors such as temperature and pressure (ECT, IAT, MAP, etc.). It can also monitor power supplies for the engine's sub-systems. Sophisticated use of these sensors can lead to online monitoring of the engine status and to detect engine (or auxiliary system) failure.

Engine's Personalized Maintenance method (EPM)

In order to increase the UAV availability, reduce men hours and lifecycle cost and to ensure cost-effective operation and sustainment, UAV's engine operation profile and maintenance has to take under consideration. By taking all the information that we have from the engine and define **loads parameter** we can achieve this goal and to optimize maintenance schedules and resources. Engine Personalized Maintenance (EPM) method provides precise engine diagnostics with possible root causes and maintenance recommendations that make it easy to perform corrective actions. The method its based on three stages.

Engine Load Factor (ELF) is a physical factor which describes the engine load due to its instantaneous load. This factor enables to normalize the engine operation hours to the real load that apply on the engine and its sub-systems and taking under consideration all the environment influences (Including low and high cycle fatigue).

By integrating the ELF over time, it gives the Engine Accumulated Load, allowing to determine the maintenance treatment that is called-for.

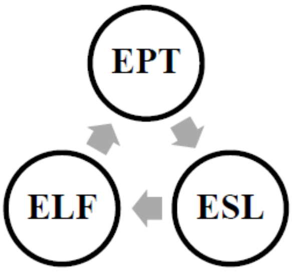
$$Engine\ Accumulated\ Load = \int_0^t ELF \cdot dt$$

Engine Sensors Limits (**ESL**) is a group of parameters with upper and lower boundaries which defines the proper range of operation of each component that is monitored with sensors and can be monitored by the ECU. This parameter allows to identify 'local' failures within the engine core or in its auxiliary systems such as oil pump, fuel pump, ignition system etc.

Engine Precise Treatment (EPT) is a physical parameter based on the fact that each rotating component has a normal operation frequency and amplitude. By measuring the normal operation characteristics in the frequency domain, it is allowed to predict a single component failure, to ensure a preventing maintenance to the engine core and/or its subsystems components.

This maintenance model is proposing the customization of Prognostic and Health Monitoring **(PHM)** treatments, practices, or products being tailored to the individual engine or subsystem components.
In this model, diagnostic testing is often employed for selecting appropriate and optimal maintenance based on the context of an engine 'genetic' content.

The three stages above are built on each other to achieve individual maintenance capability for each engine, but using each stage as an input to the other stages can result in greater accuracy.



By collecting a large amount of data from UAV's engine operation, using artificial intelligence and neural networks capabilities it is possible to reach the goal of personal maintenance for each engine and its auxiliary components and all that implies.

Precision maintenance refers to the tailoring of maintain treatment to the individual characteristics of each engine. It does not literally mean the creation of maintain treatment or spare parts replacing that are unique to an engine, but the ability to classify individuals' components into subpopulations that differ in their susceptibility to a particular failure, those engine 'diseases' they may develop, or in their response to a specific treatment.

Altogether, this approach can lead to higher availability of propulsion units, lower maintenance costs (both spare parts and personnel hours) and longer life-cycles.

Electro-Magnetic Interference and the UAV Power Plant

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Keywords: UAV; EMI; Susceptibility; Radiation; keyword 5

The growing number of UAV applications in military and civil applications led to stringent requirements for compliance with formal international design standards regarding electro-magnetic interference. The design and development process of an UAV engine cannot readily therefore be adopted from existing off-the-shelf automotive or aerospace systems.

Most of the UAV platforms are using a wide variety of electronic payloads that need to operate at their full operational envelope with no interference or degradation in performance. The UAV power plant and its build-up may include large sources of interference such as ignition systems, actuators, motors and cable assemblies.

The UAV engine development process should not therefore be supported only by analysis, simulation and test cell ground runs. This presentation shall describe proper EMI design methodologies, EMI testing methods for air-breathing engines, real-life examples of engine interference sources, and engine-platform integration issues.

EMI compatibility testing for an UAV engine includes a set of susceptibility tests for radiated and conducted emissions that should be performed using the actual platform or a simulation source.

In addition, the engine is operated for testing the effect of radiated and conducted emissions. EMI testing on the actual platform is not always possible, so the alternative testing environment is the EMI laboratory. This presentation shall describe methods for operating internal combustion engine components in a “clean room” enclosure without fresh air supply.

EMI compatibility problems may also rise at a late stage of the engine or platform lifecycle, mainly with the introduction of new payloads, so the testing and problem solution process becomes much more complicated. Propulsion engineers should also be familiar with the basic rules of design for EMI compatibility.

Poster presentations

Theoretical Investigation of a Boron Loaded Gel Fuel Ramjet

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Keywords: Ramjet, Boron combustion, Gelled fuel

A numerical simulation of a ramjet combustor with gel fuel and boron has been conducted. In the frame of this study, a parametric investigation was performed, and the ramjet engine performance was evaluated.

The ramjet is an air-breathing propulsion engine, which relies on the ram effect for compressing the entering air, thus, eliminating the need for a compressor and a turbine; however, it requires a high speed flight for good efficiency.

In the present research, the ramjet engine fuel is gelled kerosene in which boron particles have been added. Boron has 140% energy per unit mass in comparison to hydrocarbon fuels and 300% energy per unit volume. Gelled kerosene is produced by addition of a gellant allowing the addition of the boron powder preventing particle sedimentation. Various studies on boron containing ramjets have been performed, however, the potential of boron energy has not been yet utilized because of complicated ignition and combustion processes.

An earlier study by Hadad *et al* (2011). showed the high performance potential of a boron loaded ramjet engine with specific impulse higher than 2,000 s. The scope of the present research was to evaluate the performance of a ramjet loaded with boron and to investigate the effect of the various parameters, such as bypass ratio and boron content. A commercial numerical CFD code (FLUENT) was used to simulate a 3D combustion chamber of a ramjet with an aft burner in which bypass air is injected.

Boron ignition and combustion have been modelled using King's model. The model divides the combustion of boron into two stages. Initially, the boron particles are covered by a boron-oxide thin layer that prevents from ambient oxygen to reach the boron core and react. After the removal of the boron oxide layer, combustion begins releasing the chemical energy of boron.

The simulation of boron combustion was assumed as time-dependent and dealt with the particle phase separately from the CFD simulation. In each time step the diameter of the boron particles and the heat release were calculated. Particle diameter and temperature change rate depended on the flow properties. The distribution of the particles was polydisperse and they were injected into the flowfield upstream of the fuel injection. In order to simulate the process of evaporation of the gel fuel and the separating of boron particles from the gel, an iterative process was used to calculate the separating point and evaporation behavior.

The results include the temperature, velocity and particle distribution flowfield and eventually the performance of the ramjet is derived. The main conclusion from the results is that significant increase in the specific impulse can be obtained under certain conditions. The increase in the specific impulse was found to depend strongly on the time of boron particle combustion completion, and the time varies with the amount of oxygen and temperature in the combustor.

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HCCI Combustion Process Management in the ICE with TCR by Control of the Methylal Reforming Products Composition

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Keywords: HCCI; ICE; WHR; TCR; reactivity control; methylal; dimethoxymethane

About one-third of fuel-supplied energy is wasted along with exhaust gases in current internal combustion engines (ICEs). This wasted energy can be recovered by various waste heat recovery (WHR) methods. The most common method is turbocharging. However, waste heat can also be used to maintain endothermic reactions of fuel reforming, often referred to as thermochemical recuperation (TCR). TCR improves ICE efficiency due to increased fuel heating value, as a result of WHR, and lean burn options, approaching efficiency of ideal Otto cycle. Hydrogen-rich reforming products (reformate) contribute to increased burning velocity, higher octane number and wider flammability limits of the mixture. In addition, H_2-rich reformate allows a very clean combustion with ultra-low pollutant formation.

Combination of TCR and homogeneous charge compression ignition (HCCI) method (HCCI-TCR) (Fig.1) enables further improvement of thermal efficiency and simultaneous formation reduction of nitrogen oxides (NOx) and particles. HCCI combustion method is governed by a chemical-kinetic mechanism, in which homogenously premixed air-fuel charge is compression-ignited. Thus, controllability of ignition timing and combustion phasing in HCCI process are the main challenges, due to the lack of ignition control element.

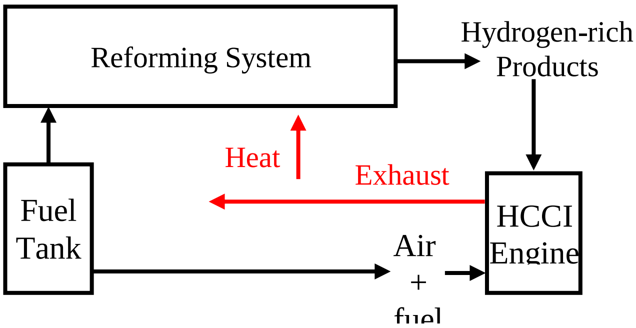

Fig.1 – Reactivity-controlled compression ignition system

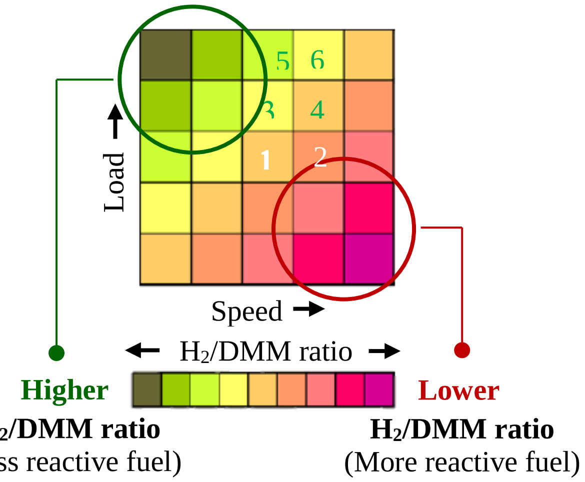

Fig. 2 – Engine fuel-reactivity demand [1]

Combustion management in HCCI engine is possible by controlling reactivity of combusted fuel, through controllable variation of fuel composition and fuel characteristics, depending on engine operation regime. At given engine regime (load and speed), the combustion timing is determined by the reactivity of the fuel injected into the cylinder (Fig.2). In case of HCCI-TCR system one primary high-reactive fuel can be used, providing low-reactive fuel by reforming.

Potential primary, alternative and high-reactive fuel for HCCI-TCR system is methylal (dimethoxy-methane or DMM) due to its unique thermodynamic properties. DMM stays in liquid phase at ambient conditions, due to its relatively high boiling point (42˚C). This allows convenient fueling without any need in new fueling infrastructure. In addition, methylal can be renewably produced through CO_2 trapping (e-fuel) and steam-reforming TCR of methylal is possible with moderate exhaust gas temperatures [2].

This research examines a possibility of managing the HCCI combustion process through the reactivity-controlled compression ignition, by controlling the methylal (DMM) reforming products composition created in a thermo-chemical recuperation (TCR) cycle using engine waste heat.

The HCCI engine model with detailed DMM combustion kinetics [3] was developed using GT-Power software to simulate the process under various operating modes. By changing the ratio between H_2-rich and low-reactive reforming products to high-reactive DMM fuel, it was possible to control an ignition delay for specific operating mode (Fig.3).

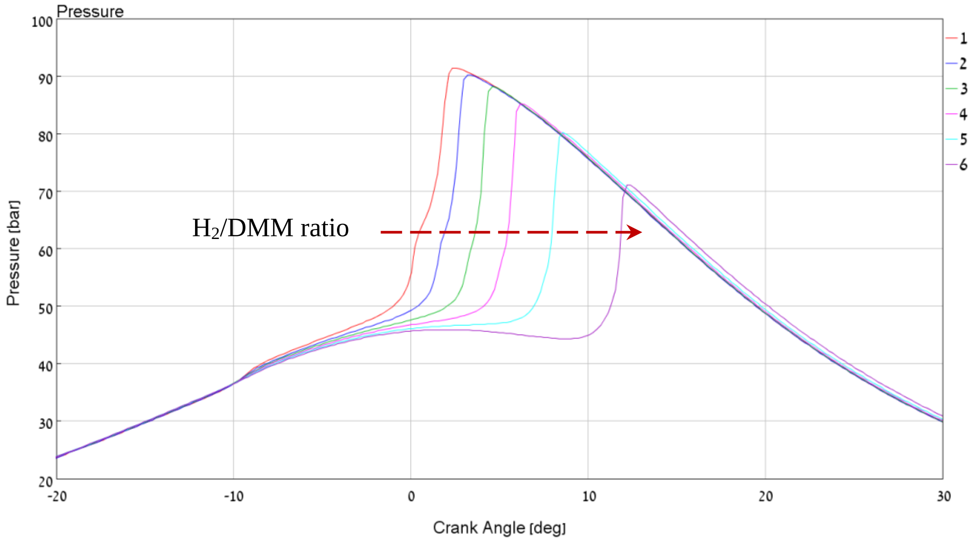

Figure 3 – The impact of H_2/DMM ratio on the ignition timing.
Engine operating mode – 2500 rpm, 4 bar BMEP, r_c=16 and EGR=0

Preliminary simulation results of typical operating modes show high engine efficiency and low NOx emissions (Fig.4), as well as ability to build control map by managing H_2/DMM ratio.

#	Speed [rpm]	BMEP [bar]	H_2/DMM	Engine Eff. [%]	CA at Max. Pressure [deg ATDC]	Lambda (at EVO)	NOx emissions [ppm]
1	2500	4	5	**47.4**	8.55	2.33	**~0**
2	3500	4	2	**47.5**	7.88	2.38	**~0**
3	2500	5	8	**47**	9.09	1.89	**3**
4	3500	5	4	**47.8**	7.29	1.95	**2**
5	2500	6	10	**44.8**	7.55	1.58	**54**
6	3500	6	5	**46.8**	5.5	1.68	**44**

Figure 4– Typical operating modes – the points are located in fig.2, r_c=16.

The presented method enables significant improvement of the engine efficiency through waste heat recovery, hydrogen burning and high compression ratio. Moreover, using hydrogen and DMM allows operation range expansion. Further research is ongoing to expand DMM speed/load map, complete system analysis, and prepare experimental setup for simulation results validation.

Acknowledgement

This work is supported by Technion Internal Combustion Engines Laboratory.

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Pump Based Hydrogen Generator

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Keywords: Hydrogen generator, fuel cells, metal hydride

Hydrogen-based fuel cells are considered highly efficient, reliable, non-toxic and non-polluting energy alternative. Like batteries, fuel cells generate electricity from an electrochemical reaction, usually of hydrogen and oxygen. Unlike batteries, fuel cells do not need recharging and will continue to produce electricity as long as a supply of fuel and oxygen is available. Their theoretical energy density may reach 10-18 times higher than batteries, which makes them extremely attractive for portable devices, small vehicles etc.

The main challenge with hydrogen fuel cells is hydrogen supply. Hydrogen is not an easy fuel to work with. It requires complicated and inefficient storage conditions due to its high volatility and inflammability and its low density. Moreover, the two main processes of hydrogen extraction, electrolysis and steam reforming, are extremely expensive.

A more efficient and useful way of producing hydrogen for fuel-cells is based on hydrolysis. Among hydrogen production methods much attention has being given to the hydrolysis of chemical metal hydride solutions(Demirci, Akdim et al. 2009).

Hydrogen generation by hydrolysis of sodium borohydride (SBH) has a theoretical ~10%wt of hydrogen content (Merino-Jiménez, De León et al. 2012). Previous studies have showed utilization of only 3%wt when NaOH stabilized solution of SBH decomposes over catalysts. Somewhat higher theoretical utilization have been claimed to be attained by direct flow of water or steam over solid powder of SBH. However, the reaction of small volume of water with large excess of solid reactive hydride salt are difficult to control and may lead to runaway reaction accompanied by high temperatures and instantaneous pressures raise (Muir and Yao 2011). The use of metal hydride solutions for "on demand" hydrogen production was previously suggested by numerous studies (e.g. (Amendola, Sharp-Goldman et al. 2000, Zhang, Smith et al. 2006, Gislon, Monteleone et al. 2009, Liang, Dai et al. 2010, Muir and Yao 2011), however, according to our knowledge, no one has succeeded to show a continuous hydrogen production in portable devices with high energy efficiency.

This research focuses on an integrated application of innovative generator - portable, friendly and efficient for the purpose of producing hydrogen on-demand for use with a hydrogen-based fuel cell. Hydrogen is produced in a chemical reaction between water and hydride material. The system controls the rate of mixing ingredients, regulating the reaction's temperature and pressure in the generator to gain the desired output hydrogen flow rate. A schematic diagram of the generator is shown in Figure 1 and an example of the energy case is shown in figure 2.

The calculated energy density of the experimental system is 208Wh/kg (taking into account the fuel cell efficiency). The operational time can be extended to 72 hours by taking 9 times more water and fuel, the energy density in that case will increase up to 965 Wh/kg.

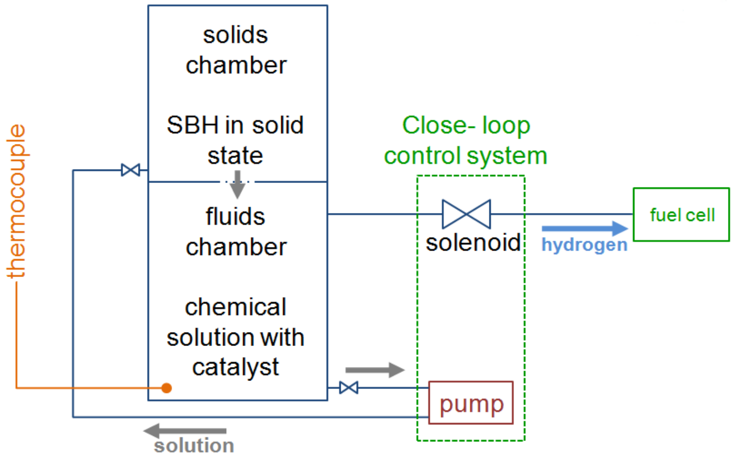

Figure 1: schematic diagram of Pump Based Hydrogen Generator

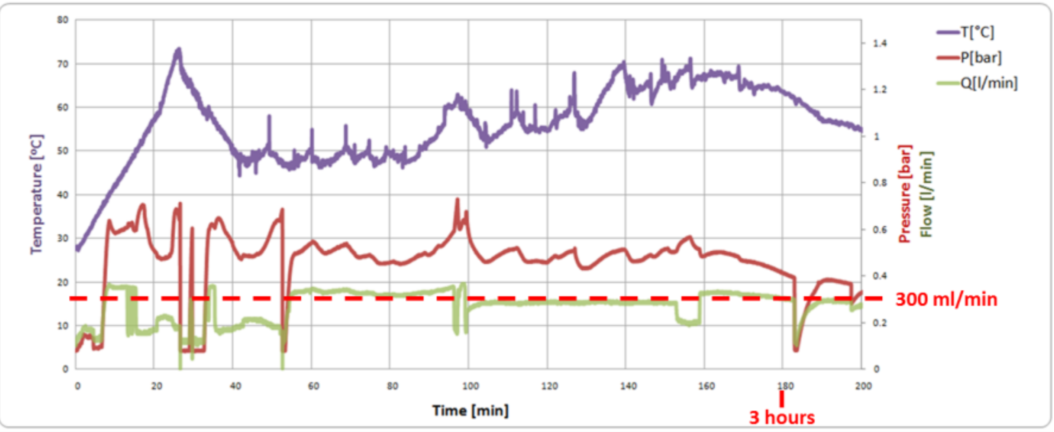

Figure 2. Example of the time-dependent parameters during 3 hours of operation.

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Storage ageing of grease in sealed-for-life high speed rolling bearings

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Keywords: Lubricant ageing; rolling bearings; grease; accelerated ageing; ageing modeling; high speed rotation experiment.

1. Introduction

The presence of a lubricant layer separating rolling elements, cages and raceways is a vital requirement for long-life and high-efficiency operation of rolling bearings. The most common lubricant applied today to rolling bearings is grease [1, 2], which is related to that far less sealing problems and much simpler machine designs are possible if oil is replaced by grease.

There are many applications, which may require lifetime lubrication.

Thermal ageing is most influenced by oxidation, and, in doing accelerated tests, the grease is heated in contact with actual solid, which may serve as a catalyst [1]. Another topic that did not receive much research attention is the effect of grease ageing on the operation of the mechanisms designed for a very long storage.

The purpose of this work was to develop a technique for assessment of a long-term storage of sealed-for-life bearings. The tested bearings were thermally aged, and then their steady state friction and temperature were examined in a high-speed spindle. These results were then compared to the performance of fresh bearings tested under the same loading conditions.

2. Model of ageing

The theoretical model proposed in the present study was developed for the design of an experiment that simulates the accelerated aging of the grease, corresponding to the real aging, developing over a very long period of time.

It should be noted that a grease would experience both oxidative and thermal degradation, which proceed via a free-radical chain reaction mechanism to form a range of products. Especially it is typical for a grease at high temperatures [3]. The aging process of the lubricant can be evaluated using the van't Hoff's law, which states that the speed of a chemical reaction changes with the temperature in such a way that an increase in temperature of 10 K roughly doubles to quadruples the reaction speed [3 – 5]. Conversely, the life of the lubricant can be doubled or tripled if the temperature drops by 10 K [5].

If at some given temperature T_0, the rate of grease aging (measuring in sec-1) is V_0, then the level of aging under the constant conditions, T_0, V_0, after the time period of t will be obviously equal to K_0, = V_0t. Following the van't Hoff's law, the rate of aging corresponding to the temperature T_0+10K will be $V = k\ V_0$, etc. Parameter k is the factor of the chemical reaction speed changes with the temperature in the van't Hoff's law. This parameter can take the values of 2; 3 or 4, depending on the specific grease type, environment and the temperature range in which the grease is operated or stored. It follows from the foregoing that the rate of grease aging, corresponding to a certain time varying temperature $T(t)$ is equal to

$$V(t) = V_0 \cdot k^{\frac{T(t)-T_0}{10}} \tag{1}$$

Total aging level, collected during the time period between the moments t_1=0 and t_2 is given by

$$K=\int_0^{t_2} V(t)\,dt = V_0\cdot\int_0^{t_2} k^{\frac{T(t)-T_0}{10}}\,dt \tag{2}$$

If the temperature of grease, T_e is kept constant during the time period t_e, the total aging level will be

$$K_e = V_e\cdot t_e = V_0\cdot t_e\cdot k^{\frac{T_e-T_0}{10}} \tag{3}$$

It follows from Eqs. (2) and (3), the levels of the grease aging will be equivalent for both cases if

$$t_e=\int_0^{t_2} k^{\frac{T(t)-T_e}{10}}\,dt \tag{4}$$

Eq. (4) means, the aging course of grease corresponding to the change of temperature according to the time function $T(t)$ during the period of time t_2 may be simulated by the storage of grease at constant equivalent temperature T_e for an equivalent period of time t_e. Providing high environment temperature, the experiment time can be greatly abbreviated.

3. Experimental details

Tribological performances were evaluated using a homemade bearing tribometer, developed specifically to this end at the Technion Tribology laboratory. The bearings should have been tested at very high rotation speed (till 100 krpm) while being loaded in both axial and radial directions. It was capable of being rotated by a suitable high-speed commercial motor and loaded radially and axially according to the required specifications. The tribometer consists of tested bearing, driving / measuring units as well as cooling systems.

Each test begins by mounting the bearing to be tested on the spindle, inserting the thermocouple in such a way as to record the outer ring temperature and strength the rigid lever that allows measuring the internal friction moment. Then, the relevant load was applied by weight suspended on the rigid lever. All tests began at a rotation speed of 12000 rpm, maintaining a constant speed for some time so that a steady state in temperature and friction moment is established, and then increasing the rotation speed by steps of 12000 rpm.

4. Results and Conclusions

The current study shows that it is possible to find a consistent equivalent transition between the conditions of natural ageing under daily and seasonally fluctuating temperature, and the conditions of accelerated thermal ageing at a constant high temperature. The test results obtained with artificially aged and reference new bearings suggest that long-term storage can significantly degrade the performance of sealed-for-life greased rolling bearings. It is also evident that a proper running-in performed prior to the long-term storage can substantially deter the ageing-driven degradation of the greased bearings.

5. Acknowledgements

We thank Prof. I Etsion for his consultations, Dr. G. Halperin, Mr. S. Nakad, Mr. O. Gutman and Mr. A. Tsipenyuk for their help in experimental part of this work. We acknowledge the support of the Israeli Ministry of Defense. Tested bearings were provided by The Barden Corporation (UK).

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Optimization of Parameters of Internal Combustion Engine

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Keywords: Optimization; parameters; internal; combustion; engine

This report is dedicated to calculations of engine using computer programs. Often the multivariate calculations that the researcher performs are called optimization. We have developed and use another method: we set the goal and limitations, and a separate optimization program (using the engine calculation program) automatically finds the optimal values of the variable parameters. Here is the simplest variant of optimization - optimization at constant rated engine speed.

Optimization goal is – **min BSFC** – brake specific fuel consumption.

Restriction in the optimization is: power not less than required. In the present case, since $n = const$, said restriction is equivalent to the restriction *brake mean effective pressure* p_e is no less than its predetermined value p_e^*. This restriction $p_e \geq p_e^*$, was used in the optimization, the results of which are given in the table below.

Other restrictions: maximum combustion pressure - p_{max}^* is not greater than its permissible value - p_{max}^*; maximum rate of pressure rise, heat-flow into the cylinder head and into the piston; temperature in front of the turbine - are not higher than the permissible values; the absence of clash between the valve and the piston (during the valve timing variation).

Varied Parameters: λ – air-fuel equivalence ratio, r_c - engine compression ratio, π_c – pressure ratio in the compressor of turbocharger, θ_b – angle of exhaust valve opening (here and elsewhere quantities of angles are measured in the crank angle degrees with zero point in TDC of power stroke), θ_b' – angle of exhaust valve closing, θ_a – angle of intake valve closing, θ_a' – angle of intake valve opening, and angle of fuel injection.

For optimization a function of the goal was formed, the minimum of this function ensured min BSFC and the fulfillment of all specified restrictions. Optimum was found by the methods of nonlinear programming (Nelder and Mead method, Powell method).

The table below shows the results of optimization of four-stroke diesel with turbocharger and intercooler. The aim of the optimization is minimum BSFC. The main (limiting) restrictions: $p_{max} \leq (\, p_{max}^* = 11.2$ MPa), $p_e \geq (\, p_e^* = 1.32$ MPa).

Engine Variant					
S	D	η_{TC}	n	Valves Number	
m		–	rev/min	Intake	Exhaust
0.165	0.17	0.653	1800	2	2

Limiting Restrictions in Optimization Process	
p_{max}^*	p_e^*
MPa	
11.2	1.32

№	Optimum Values of Varied Parameters							Part of Results of Optimizations				
	λ	r_c	θ_b	θ_b'	θ_a'	θ_a	π_c	ISFC	BSFC	p_e	p_{max}	P
	–	–	Degrees of Crank Angle					g/(kWt.h)		MPa		kWt
1	2.14	11.4	117	384	328	587	2.68	188	230	1.32	11.21	552
2	1.75	14.0	109	374	345	564	2.31	192	235	1.32	11.21	552

In the table: S – piston stroke, B – bore, η_{TC} – turbocharger efficiency, “Valves Number” - the number of intake and exhaust valves at every cylinder, n – engine speed, P - engine power.

Optimization № 1 found optimal r_c = 11.4. This compression is optimal for minimum fuel consumption, but undesirable for starting a diesel engine. Therefore, optimization №2 has been done. In this optimization, the minimum compression ratio is limited to 14.

Powertrain for the 2019 SAE Student Car

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Keywords: Formula; SAE; Engine; Powertrain

Background

The Technion Formula SAE team is designing the seventh iteration of its vehicle. After switching to a single-cylinder KTM EXC-F 450 engine in 2017, the team is optimizing the powertrain design for optimal performance. Due to a significant weight reduction in the entire car (~10kg), the team decided to stay with a naturally aspirated engine due to the possible drivability issues that could arise from a significant increase in power.

Engine Performance

However, to increase the power and torque of the engine for optimal lap times, the team will change to a piston with different geometry to increase the compression ratio from 11.8:1 to 12.8:1. In order to optimize the engine's performance and the auxiliary engine systems, GT Suite model was built to predict engine performance and data such as air flow and volumetric efficiency. The model was built using physical properties of the engine and its geometry as well as certain boundary conditions that were determined using tests performed last year. After building the engine model, the intake and exhaust systems were optimized to find the right balance between vehicle integration and performance.

Intake System

The intake system is significantly different than the previous year's after discovering that the previous system was far from optimal. The volume of the plenum/airbox was kept 5.5L which is the maximum that fit in the rules limitations, and the optimal for the engine perfomance. This change in volume is optimal according to the GT analysis. The restrictor and runner length were optimized in Ansys CFD simulations, the optimal performance of the intake were checked at 6000 RPM and 9000 RPM of the engine. In addition, the throttle diameter and restrictor (20mm restriction mandatory by Formula Student rules) geometry were determined through CFD analysis and our custom-made throttle was designed. Instead of using a butterfly-type throttle, the team is designing a slider throttle and a different type of throttle that swivels open, which will both be tested. The maximum mass flow rate was found with a throttle diameter of 25mm and with the addition of a bell-mouth shape at the inlet to guide the air into the throttle body.

Cooling System

This year's cooling system was modified for aerodynamic reasons. The system consists of two similar sized radiators. The previous year's radiators were in front of the rear wheels and lowered the downforce of the car by 80[N] at 80 [km/h]. As a result, the system was moved underneath the driver seat in an aerodynamically strategic position to provide more space for aerodynamic devices and to increase in general the lateral acceleration and cornering speeds. To improve the air flow rate through the radiators, air ducts were fitted. To decrease the pressure after the radiators, a special rear duct was made to direct air from the radiators to lowest pressure place in the car. To improve the air mass flow rate furthermore, the front wing of the car was designed to create outwash and direct "clean" air to the air ducts.

Fuel System

Last year fuel system was based on an aluminum fuel tank. This year, the tank is build from carbon fiber to lower the weight. The tank has a trapezoidal shape which allows for easy integration in the car and includes a baffle and anti-sloshing foam to prevent air in the fuel inlet during cornering. In order to lower the weight even more, the fuel pump was changed to a lighter one (from 400 [gr] to 70 [gr]), the diameter of the fuel pipes was reduced to 3/16" to lower the pipes and connector weight. A new fuel pressure regulator was fitted with a new light weight housing. A new high mass flow Bosch injector was placed in the intake. The new injector improved the fuel atomization with two conical sprays. The sprays are directed exactly to the two intake valves of the engine.

Acknowledgement

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Controlled Radical Production by Non – Thermal Plasma

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Keywords: ignition; plasma; homogenous charge compression ignition; plasma assisted combustion

Since the early days of IC engines, plasma has played a key role as an ignition method. During the past decade and a half, ever-growing and restrictive demands for increased engine performance and pollutant emission reduction have stressed the need for ignition and combustion processes optimization.

As a result the modern IC engine is controlled by an ECU (Engine Control Unit) which processes information supplied by various sensors in order to estimate the desired fuel injection and ignition timing. As part of the same general effort an extensive investigation of homogenous charge compression ignition (HCCI) engines has been conducted all around the world since the late 1990s [1]. It is important to note that the main purpose of an HCCI engine is to enable useful ignition of lean premixed mixtures at relatively high compression ratios. This is achieved by indirect influence of radical generation through chemical kinetic manipulations of the gas mixture, mostly by controlling its chemical composition and temperature.

In the past two decades, Plasma Assisted Combustion (PAC) has been widely investigated, mainly in the form of Nanosecond Repetitive Pulse (NRP) discharge. In this process, a voltage of several kilovolts is repeatedly applied for about 10 ns at frequencies of a few tens of kHz.

This method has been proven efficient for flame stabilization and reduction of lift-off height [2], expansion of flame extinction limits [3], in cylinder fuel reforming [4] and multiple sites flame initiation [5]. The apparent advantages are all attributed to reaction enhancement by free electron excitation collisions, causing an increase in radical concentration and ultrafast gas heating. In recent years, many fundamental studies of PAC were carried out. These include detailed investigations of the influence of electrical discharges on species concentration and gas temperature [6], identification of involved mechanisms [7], [8] and the influence of NRP in turbulent flow [9].

One major drawback of all of these highly sophisticated methods is the limited ability to measure the state of the intake charge and its chemical advance towards ignition. The measurement methods available today are mostly conducted through several engine working cycles and adjustments are retrospectively made.

Our present research was initiated by the idea of using electric breakdown voltage measurements through the gas mixture to evaluate its density. Such measurements can be conducted at high frequencies, potentially even during a single working cycle.

The relation between the gas breakdown voltage and its density was already discovered in 1889 by Friedrich Paschen and the basic theoretical foundations were established in 1915 by John Sealy Townsend [10]. In the present research we have conducted breakdown experiments on a conventional automotive sparkplug in nitrogen and generalized Townsends' basic theorem for non – uniform electric fields, produced due to the complex geometry of the sparkplug.

At the present stage, we conduct a numerical investigation of the possibility to restrict the NRP method to the streamer discharge regime. This regime can potentially cause volumetric radical generation while maintaining low temperature increases. In addition, we investigate the relation between the change in breakdown voltage between NRP pulses to the advancement towards ignition. If a physically controlled streamer phase restriction is possible, the breakdown voltage between pulses will change with the electrical charge density that exists in the gap. Since these charges are ultimately responsible for radical generation, we suggest that such a method can be applied for both ignition and combustion, optimization and control.

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A New Modified Diesel Cycle for Small Aircraft Operating at High Altitude Conditions – A Numerical Simulation

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Keywords: Small aircraft; Diesel engine; High altitude conditions

Small aircraft for long range missions are usually propelled by a suitable propeller driven by a gasoline or a diesel engine. Specific power (power to weight ratio), specific fuel consumption and appropriate performance map at high altitude are paramount requirements. The aim of the present research project is to theoretically examine a new idea in which an in-cylinder steam reforming mechanism is suggested to significantly improve the cycle efficiency and performance map of the engine at high altitude. This is done by using a special catalyst piston head coating and pre-injection of small amount of fuel. The present examination will be performed by analyzing this cycle with a tailored self-developed computer algorithm that will include also the relevant chemistry and thermodynamics of the special designed cycle. In the 1st stage, a comprehensive model of a conventional diesel has been developed and presented in the attached document. In the 2nd stage, the model will be modified to include the chemistry and thermodynamics of the special designed cycle. The cycle was computed while accounting for the effects of:

- Altitude
- Compressive Flow
- Heat Transfer by convection (according to Annand correlation)
- (C_P, C_V, γ, k) varies with temperature
- Turbocharging
- Multi fuel injection by using Common Rail system (pre-injection of small amount of fuel in high pressure)
- Different start of injection (SOI) crank angles (CA)
- Ignition delay of the pre-injection

Table1 - Results

Height [ft]	0		10,000		20,000	
Partial load [%]	50	100	50	100	50	100
Efficiency $[\%]$ *Turbo*	58.8	53.1	58.6	52.8	58	52.2
Efficiency $[\%]$ *NO Turbo*	58.1	52.5	57.4	51.8	55.9	50.5
$BSFC\left[\frac{gr}{hr \cdot kW}\right]$ *Turbo*	153.3	155.8	168.3	163.8	202.7	180
$BSFC\left[\frac{gr}{hr \cdot kW}\right]$ *NO Turbo*	168.5	164.3	200.8	180	314	218

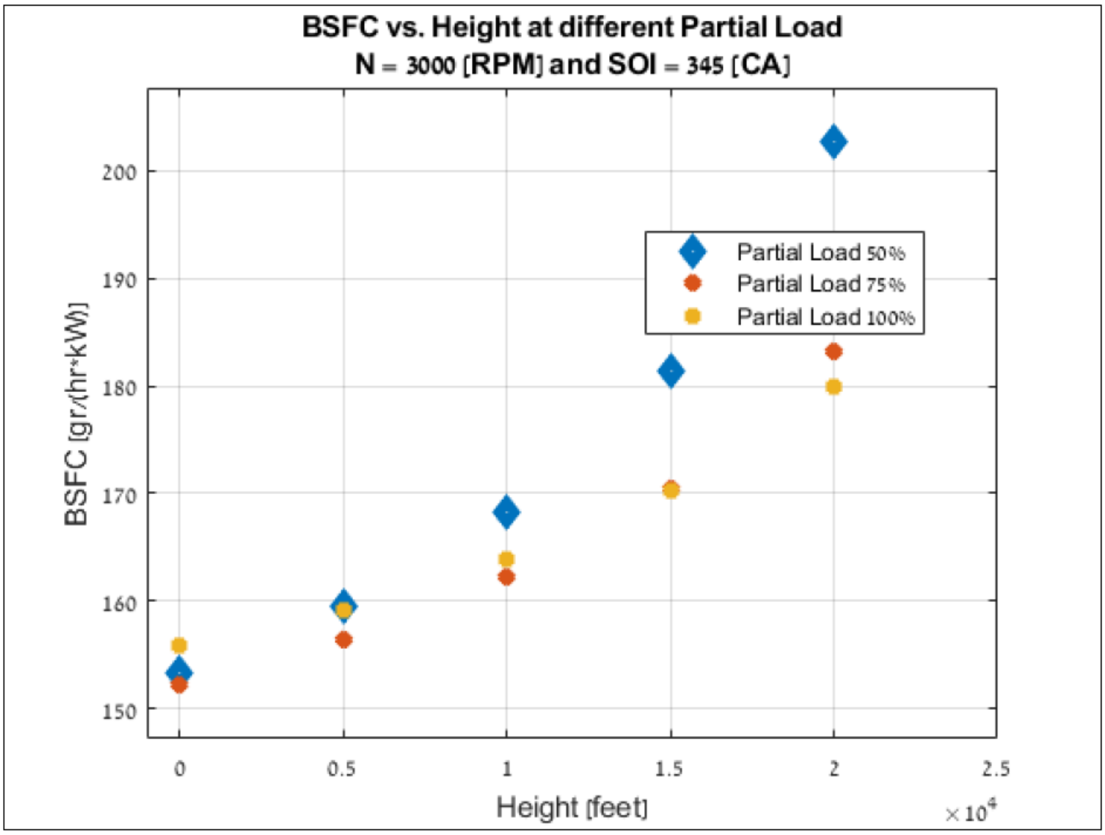

Figure 1 - BSFC vs. Height at different Partial Load

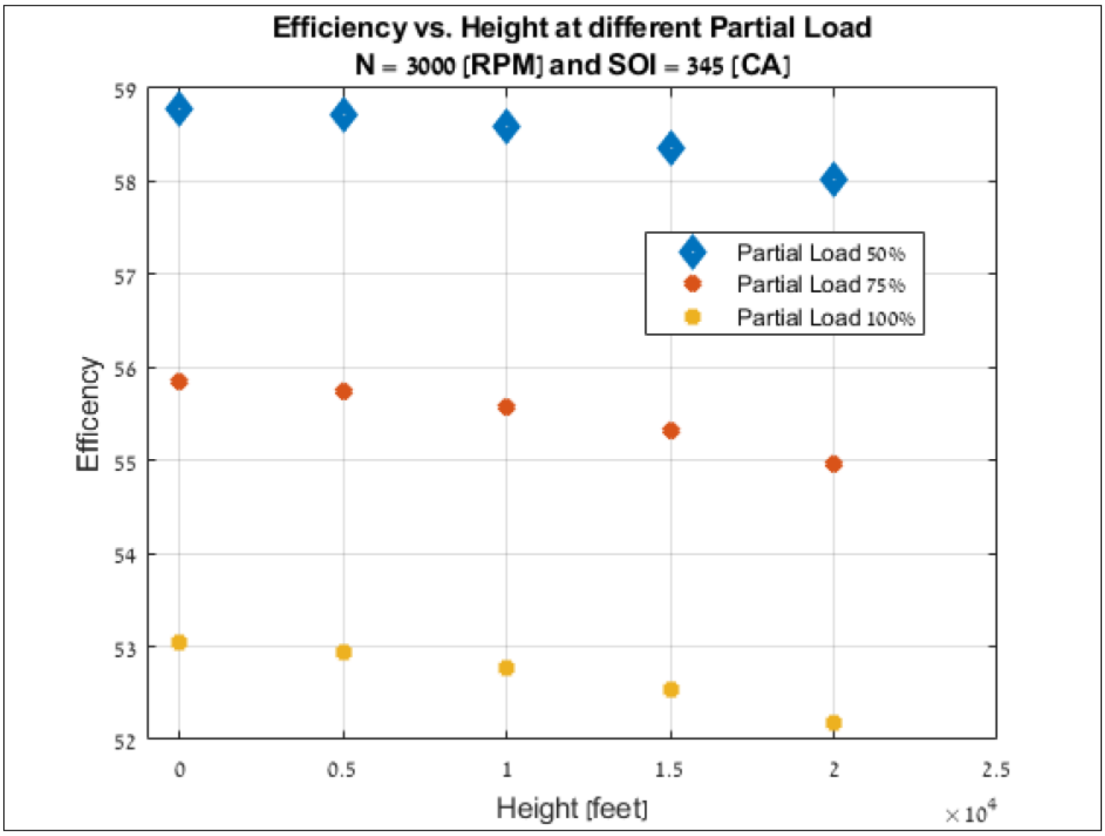

Figure 2 - Efficiency vs. Height at different Partial Load

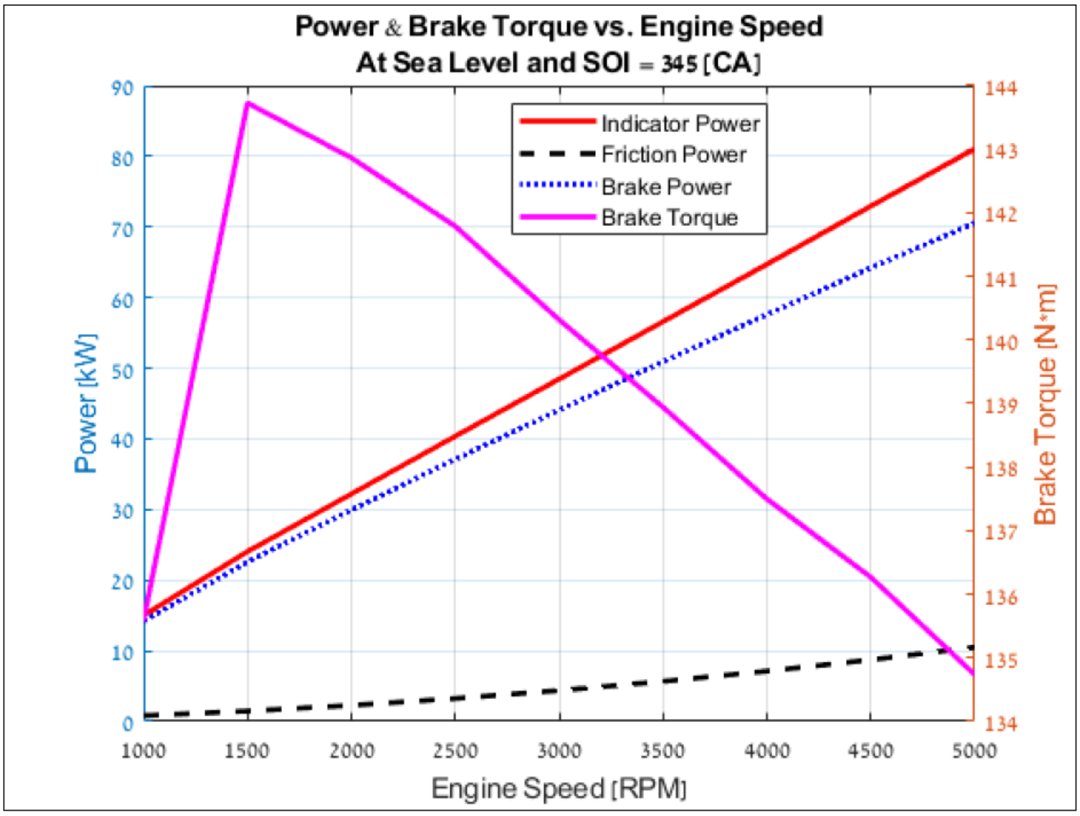

Figure 3 -Power & BrakeTorque vs. Engine Speed

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Reforming-controlled compression ignition

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Keywords: Thermochemical recuperation; Reactivity-controlled; Pollutant emissions;

In the last decades, there has been wide interest in reducing emissions and fuel consumption from vehicles. Tough regulation due to environmental, economic, and political circumstances leads to the development of cleaner and more efficient propulsion technologies. The modern ICEs should utilize low-carbon and renewable fuels for diminishing greenhouse gas emissions and oil dependence, and be more efficient.

Homogenous Charge Compression Ignition Engines received considerable attention for their high efficiency and low emissions (Yao et al, 2009). High compression ratio combined with very high heat release rate enable approximating the ideal Otto cycle, thus making HCCI engine highly efficient. The HCCI combustion is characterized by a relatively low temperature since the excess air (due to working with a lean mixture) absorbs the heat released during the combustion. This leads to extremely low particulate matter (PM) and nitrogen oxide (NOx) emissions and decreases the heat transferred to the walls. However, combustion controllability problem, limited operation range (Saxena et al, 2013), too high-pressure rise rate at high loads (Eng, 2002), and some other challenges hamper market penetration of HCCI engines. Several methods have been proposed and are investigated to resolve the mentioned above problems. These methods can be classified into two main groups, the first is based on temperature control and the second - on reactivity control. Changing the intake temperature or pressure, varying Lambda, and exhaust gas recirculation (EGR) are some first group methods. These methods show a potential for ignition timing control but mostly are limited and do not enable engine operation in the HCCI combustion mode in the whole range of operating modes (Yao et al., 2009).

RefCCI is an innovative method of CAI combustion control based on fuel reactivity control. This method provides a solution for the ignition-timing control, the high level of CO and HC emissions, and the limited operating range at low and high loads. According to this method, the exhaust gas available energy is recycled in a chemical reformer to sustain endothermic reactions of a water-DME mixture conversion to a hydrogen-rich reformate. These reactions occur mostly at relatively low temperatures (~250-350°C) and are supported by a bi-functional catalyst (Oar-Arteta et al.) The bi-functional catalyst consists of acid and metal materials and therefore allows the simultaneous existence of several reactions. This heat delivery system scheme is displayed in Figure 1. The engine is fed by the non-reformed DME and the hydrogen-rich reformate in a variable ratio depending on the engine operation regime. The non-reformed DME is injected directly into the cylinder by a standard diesel injector. The hydrogen-rich reformate is separately injected by a gas injector, under elevated pressure, to allow enough fuel to be supplied into the cylinder under reasonable injection duration. The fuel to be reformed is compressed in a liquid phase. Hence, the reforming is performed at elevated pressure according to the principles described in (Poran, Eyal et al.).

Combustion properties of the high- (DME) and low-reactivity (H2 with some amount of CO) fuels considered in the reported study are presented in Table 1. Thus, combustion timing control is achieved by varying the hydrogen-to-DME ratio. Richer and leaner hydrogen fuel-mixture is less- and more reactive, respectively. The fuels are injected into the cylinder separately and this allows full combustion control even at transient regimes. Both DME and hydrogen have wide flammability limit allowing unthrottled engine operation at low loads.

Table 1. Combustion properties of relevant fuels [32,39].

Parameter	Dimethyl Ether (high-reactivity fuel)	Hydrogen (low-reactivity fuel)	Carbon Monoxide (low-reactivity fuel)
Molecular mass, g/mol	46.07	2.02	28.01
Chemical formula	CH_3OCH_3	H_2	CO
Lower heating value, MJ/kg	28.9	119.7	14.3
Octane number	-	130	106
Cetane number	>55	-	-
Flammability limits by λ (upper/lower)	0.19/1.99	0.14/10.08	0.15/2.94

This study utlizes multiple tools to model the RefCCI system. 1-D model is utlized to exmaine th energy balance of the system. The model assumes homogenous and single zone combustion in th cylinder. CFD model is used to analyze the combustion in the cylinder more accurately. Differen injection methods are investigated to find the ideal injection method for, on one hand, reducing engin ringing in high loads, and on the other hand, avoiding efficiency reducing due to a unwilling ignitio timinng.

As seen from the Table 2, the higher values of system efficiency improvement are achieved typicall at lower engine efficiency regimes. Lower engine efficiency is observed usually at low-speed an high-load regimes because of higher heat losses. Exactly at these regimes, combustion of less-reactiv fuel with higher hydrogen content is required. As mentioned previously, as long as more hydrogen i combusted, more waste heat is recovered. This finding is important and shows a way to moderat the efficiency variance in the RefCCI engine at various regimes.

Table 2. First law analysis of some representative cases based on the illustration in Figure 11. Cases 1,2, and 4 shov different speeds at the same load and cases 3-6 - different loads at the same speed.

Case	units	1	2	3	4	5	6
Speed	RPM	1500	3500	**2500**	**2500**	**2500**	**2500**
BMEP	bar	**4**	**4**	3	**4**	5	6
H_2/DME ratio	-	4.6	2.2	1	2.6	3.4	4.8 (10% EGR)
Fuel to be reformed	%	45.5	29.2	25.0	36.0	39.0	47.9
Products	%	50.4	32.5	26.8	39.5	43.4	53.5
Total energy of the combusted fuel	%	104.9	103.3	101.8	103.5	104.4	105.6
System Efficiency	%	48.3	47.9	49.2	49.5	48.9	46.8
Heat transfer	%	21.6	16.7	14.7	17.4	19.0	23.3
Exhaust	%	35.0	38.7	37.9	36.6	36.5	35.5
Engine Indicated Efficiency	%	46.0	46.4	48.3	47.8	46.9	44.4
Efficiency improvement	%	5.0	3.2	1.9	3.6	4.3	5.4
Recycled energy	%	4.9	3.3	1.8	3.5	4.4	5.6
Exhaust losses	%	30.1	35.4	36.1	33.1	32.1	29.9

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The benefits of Inverted Brayton cycle and Concept for CHP plants based on Low-Power Micro Turbine Generators

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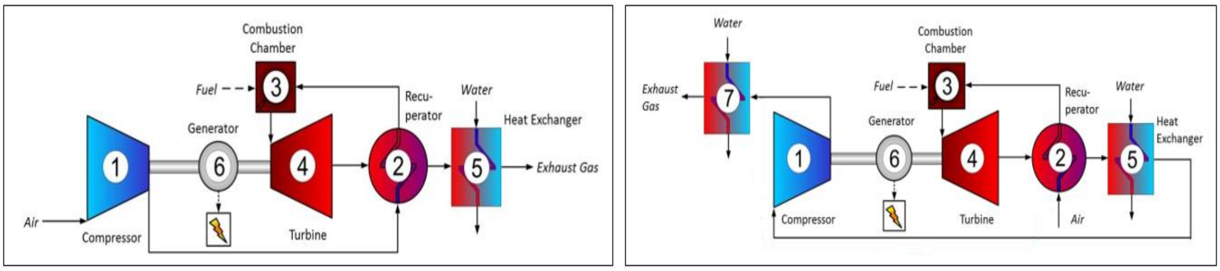
Keywords: CHP plants; Micro Turbine Generators; Conventional and Inverted Brayton cycles

Significant use of Residential CHP plants (el. power P_{el} = 1-5 kW; heat power P_h = 3-12 kW) would enable dramatic reductions in primary energy use and concurrent CO_2 emissions. Low-power MTG are best suited for the operation as their parts to produce electricity and use the waste heat for space and water heating [1,2]. MTG can use different fuels, work together with alternative energy sources and have the required environmental safety. However, their potential can be realized only in mass production with low Initial Costs and long lifetime [1,2,3]. There is the possibility to meet these requirements by MTG design based on unification with mass production automobile Turbochargers [2,3].

However the small Turbochargers have excessive losses of energy conversion, respectively low compressor η_c, turbine η_t, thermal η and MTG common efficiency η_e. It is also impossible to increase the compressor pressure ratio π_c to the optimum [2,3]. This may reduce the efficiency of low-power MTG. Two possibilities were discussed for its improving with the use of simulation methods («TEST: The Expert System for Thermodynamics» [6]) with real values of η_c (0.7±0.6), η_t (0.65±0.5) for small-sized turbochargers such as Garret GT15 and recuperators Eff_{rec} (0.75±0.5) and heat exchangers Eff_{intc} (0.7±0.3) efficiency.

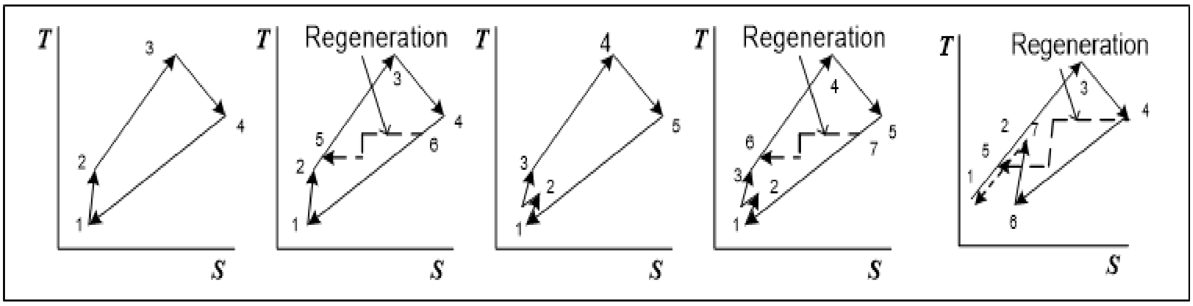
It was found, that the efficiency of MTG increases from an unacceptable level (5-7%) for the conventional simple Brayton S-cycle to a low level (to 13%) for complex intercooled recuperative ICR-cycle (Table 1, Figure 1a,2a-d). The use of complex cycles is economically impractical because it can lead to the MTG complication and the increase of its cost.

It was also established, that Inverted Brayton cycle (IB-cycle) has the application potential [4, 5]. Its Heat scheme is clear from Figures 1b, 2e. To reduce the compression work, gas cooling is required, so the water heat exchanger 5 is an element of the Heat scheme. IB-cycle using increase of thermal Efficiency η compared with all conventional cycles due to application of the medium-sized turbocharger such as Garret GT25 with higher η_c (0.76±0.5) and η_t (0.74±0.5) efficiency. IB-cycle thermal Efficiency η depends not only on heat exchanger efficiency Eff_{hex} (0.8±0.3) but also on the temperature of the cooling water t_W.



a) b)

Figure 1.Various CHP Heat schemes based on MTG:
a) - conventional Brayton cycle; b) - Inverted Brayton cycle [4].



a) b) c) d) e)

Figure 2. Low-Power MTG conventional Brayton cycles:
a) - simple (S-cycle); b) - recuperative (R-cycle); c) - intercooled (IC-cycle);
d) - intercooled recuperative (ICR-cycle) and e) - Inverted Brayton (IB-cycle).

Table 1. Comparison of various MTG Brayton cycle efficiency (P_{el} = 3 kW)

Type of cycle	S-cycle	R-cycle	IS- cycle	ISR- cycle	IB-cycle (t_W,^{0}C)		
					20	40	60
Thermal Efficiency,%	5.4-7.2	10.7-11.2	7.5-8.6	12.5-13.2	14.5	12.2	9.8

Conclusion

The increasing of residential CHP plants' efficiency based on low-power MTG and using Conventional Brayton cycles are not very effective without increasing MTG cost. At best, it is possible to use R-cycle. Low MTG thermal and common efficiency is compensated by using the waste heat for space and water heating with an increase in the CHP efficiency up to 70-75%. Therefore, the fundamentals of the new concept for CHP plants based on low-power MTG were submitted for discussion. The prominent design principles are:

- MTG design is based on unification with the mass production of automobiles with low cost Turbochargers. This will provide the required reliability and reduce their Costs;
- application of the Inverted Brayton cycle, which may have a higher thermal and common efficiency. Other advantages include simplicity of construction because the combustion occurs on atmospheric pressure and there is no need to use compressors for fuel supply; adaptability to different fuels, opportunity to work together with alternative energy sources, providing the required environmental safety and so on.

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Particle emission characteristics of an ICE fed with hydrogen rich-reformate

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Our reliance on combustion produces several problems such as fuel crisis, environmental and health issues. All of these factors appeal to the internal combustion engine (ICEs) development towards notable engine technology with an objective of energy saving and emission reduction. In this view, over the last decade, the use of alternative low carbon intensity gaseous fuels is being promoted to reduce the reliance on fossil fuel and engine emission. Particularly, thermochemical recuperation (TCR) is a promising waste heat recovery method that enables utilization of the engine waste heat together with onboard hydrogen production, which results in significant improvement in thermal efficiency and a dramatic reduction in gaseous pollutants emission (Tartakovsky and Sheintuch 2018). A novel approach of High-Pressure TCR was suggested in the Technion and enables eliminating well-known major drawbacks of TCR, such as engine power loss, backfire, etc. together with a significant rise in engine efficiency and mitigation of gaseous emissions (Poran and Tartakovsky 2017). Although, the emerging technology eliminates several issues simultaneously. However, in the present study, an unexpected rise in particulate matter (PM) emission was observed despite the combustion of a hydrocarbon-free hydrogen-rich methanol steam reforming (MSR) products containing 75% mol. H_2 and 25% mol. CO_2. In the existing literature, the reason for this phenomenon has not been completely understood. Present work focuses on understanding the physics of formation of particles in a direct injection ICEs fed by hydrogen-rich gaseous fuel.

In the reported study, experiments are performed to investigate the PM emissions of a direct injection SI engine fed with MSR reformate, and the results are compared with a baseline case of engine feeding with gasoline at the same engine load and speed. The results of particle number concentration and size distribution measurements performed with Engine Exhaust Particle Sizer spectrometer show that the total particle number emission of engine fed with MSR reformate is 170% higher compared to gasoline combustion. The particle mass size distribution shows that MSR-fueled engine emits 42% higher mass in accumulation mode than the gasoline-fed counterpart. The particle number size distribution results indicate that a remarkable difference between the particles emissions with MSR and gasoline fuels lies in nucleation mode, where the peak particle concentration occurred about 10 nm for both the fuels. The higher PM attributed the combined effect of direct injection and intrinsic properties of the hydrogen-rich MSR reformate. The latter lead to enhancement of the fuel jet and flame interaction with the lubricant oil, hence resulting in the increased particles formation. Besides, MSR fuel generates water as by-product presumably may react with other elements during the post-combustion process and influences the particulate emission.

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