

The effects of chemical additives on the ultra violet output of MTV

by Joseph Slattery

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The effects of chemical additives on the ultra violet output of MTV

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Project submitted as part of the requirements for
the award of BEng (Hons) OME

March 2024

Declaration of Originality

I, Joseph Robert Slattery declare that I am the sole author of this Project; that all references cited have been consulted; that I have conducted all work of which this is a record, and that the finished work lies within the prescribed word limits.

This work has not previously been accepted as part of any other degree submission.

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Date : 21/03/2024

ABSTRACT/SYNOPSIS

The future of weapon threat systems should always be considered for the possibility of informing research. An up and coming threat may be posed by the use of the ultraviolet spectrum to target military vehicles and for this reason it is important to  researching into possible countermeasures to these threats before it is too late. MTV  is a commonly used pyrotechnic in current countermeasures against infra-red threat systems, due to its long service life it is a well understood composition and provide a good foundation to adapt and improve to a future threat. The method of ultraviolet production in MTV is poorly understood and need to be improved, by using existing literature on pyrotechnic combustion along with an understanding of chemistry and physics this report explains the main method MTV used to produce ultraviolet. This leads into the research into alternative material that can possibly be used to produce an even greater effect, aluminium has been used to increase the heat of detonation in explosives for years, can the effect translate to a pyrotechnic to increase the heat and therefore the ultraviolet output. Other compositions have been looked at for UV such as sodium nitrate however this was a long time ago when technology was more limited, this report modernises this and looks at it in context of a modern pyrotechnic. Concluding in a recommendation of which compositions to take forward and research further. 

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CHAPTER 1 INTRODUCTION

1.1 INTRODUCTION

Ultraviolet (UV) pyrotechnics is a specialized field within the broader realm of fireworks and pyrotechnics displays as well as having potential future defence applications to combat new threats. UC 5 pyrotechnics involves the use of materials that emit ultraviolet light when ignited, creating unique and visually striking effects.

The reason for this research stems from the current threat environment that military vehicles find themselves in. Current threat systems use Infra-Red (IR) detection to assist with targeting the vehicles which is why current research investigates the use of conventional pyrotechnics in order to confuse and distract these systems and protect the vehicle.

However, a potential future threat could arrive from the use of UV spectral imaging to identify targets were by the weapon system is using the UV signature of the target rather than the IR signature currently used. 6 For this reason, it is important to have a countermeasure to this threat should it ever come to be a reality. If research is delayed until a threat has already come into use, then lives could be lost while research attempts to catch up to the threat. By beginning research now it is possible to develop a better understanding of what will be needed in the future and prevent a long delay if a UV countermeasure system were to ever be needed. Therefor this project exists to investigate the possibility of producing UV light for the purposes of distracting or masking a target from the viewer allowing the target to survive a potential lethal engagement. 7

1.2 AIM

The aim of this project is to develop a greater understanding of the UV output of Magnesium Teflon Viton (MTV) and what affect 8 different chemical substitutions may have on this output with the ultimate goal of increasing the UV and Visible output. This will be done by understanding the chemistry of electromagnetic radiations (EMR) production from pyrotechnics by modelling there combustion to get products produced for emission spectra comparison along with adiabatic flame temperature for use with Stefan-Boltzmann law and Wien's displacement law. By using the Stefan-Boltzmann law along with Plank's law 9 blackbody radiation, it is possible to determine the expected spectral radiance of the

composition and the Wien's displacement law will allow for a calculation of the point of maximum spectral output to see if the blackbody curve has shifted. This information will then be used to inform further research into the compositions with the eventual production of small samples for testing to ensure they have comparable productions to the modelled compositions.

1.3 OBJECTIVES

Objective 1: Investigate possible alternative compounds

In order to improve MTV the method chosen is to replace one of the components with a different material in order to produce an altered composition that would increase the UV output or possibly reduce the IR output. Due to there being a very large number of compounds that exist, a literature review would need to be conducted to identify materials that show strong potential to do either or both of the aforementioned. By conducting a literature search it is possible to reduce the number of potential compositions down from thousands to a small handful that have justifiable reasoning for why they may provide the desired effects.

Objective 2: Identify current UV properties of MTV 10

To be able to improve upon current UV production it is first important to have an understanding on what the standard output of MTV looks like. This initial step will then be used as a baseline in order to compare the altered compositions to see if a desirable improvement has been made.

Objective 3: Investigate compatibility issues

All energetic compounds including pyrotechnics are known to react unfavourably if introduced to non-compatible compounds; this reaction can range from rendering the composition inert to causing an unwanted ignition. Therefore, a compatibility investigation must be carried out to insure that whatever altered composition is being made would be stable and not cause any undesirable effects such as those mentioned above.  11

Objective 4: Produce simulation of compositions

Once the above process has identified a set of suitable materials, evaluation can begin in order to ascertain the data needed for comparison with MTV. For this, the same method must be used to evaluate all of the altered compositions as well as the MTV to ensure that all the data is in the same format and consistent. In order to obtain the data needed a thermochemical analysis code known, as Explo5 will be used for all composition simulations.  12

There should be a section in Chapter 1 that summarises all the chapters.

CHAPTER 2 - RESEARCH & REVIEW OF LITERATURE

2.1 LITERATURE REVIEW

Research on the matter of UV emission in pyrotechnic compositions is currently limited due to there not being an immediate or historical need along with the limitations in technology that are only now making UV targeting systems a potential threat. Research has however been done into non-pyrotechnic materials that can produce UV as well as other methods of UV production which have been studied for potential other uses outside of defence. These alternative researches may have a degree of read across in order to inform what can be used to produce a UV pyrotechnic composition.

To understand where to begin with identifying compounds for testing it is important to first get a clearer understanding of exactly what is required and a background of information in the general field of UV. Ultraviolet light is emitted between the wavelengths of 10-400nm which is typically broken down into 3 distinct sections: UV-A between 400-315nm, UV-B between 315-280nm and UV-C between 280-100nm [1]. UV-C covers the widest section of the UV band and its rays are the most harmful to humans; however, they are completely absorbed by the earth's atmosphere [2]. UV-B rays are typically associated with causing sunburn however; approximately 95% of UV-B is attenuated by the atmosphere and absorbed by the Ozone layer [3]. Due to the concerns raised regarding a system able to track a target over a long distance, further research will focus on the range of 280-400nm hereby referred to as UV-A+B. This waveband is able to travel the furthest in our atmosphere and is what would be expected for any vehicle to reflect from the sun so the assumption can therefore be made that this is what a targeting system would be looking for.

Looking at the general production of UV light, research focuses on three common methods that produce in the wavelengths of interest, the three methods being black lights, Incandescent lamps and gas-discharge lamps. Fluorescent black light tubes follow a production process similar to regular fluorescent tubes, the primary distinction being the use of a phosphor that emits UVA light rather than visible white light inside the tube. Specifically designed for black lights known as Black Light Blue (BLB) when in industrial use, incorporate a dark blue filter coating on the tube as can be seen in Figure 1 below. This coating filters out most of the visible light, allowing for the observation of its fluorescence effects [4]. When in operation these tubes emit a subdued violet glow.

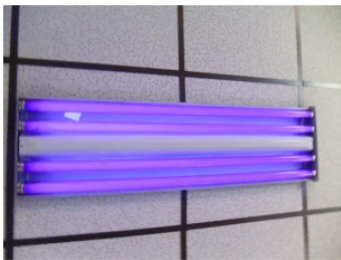


Figure 1 - Four F40T12/BLB 48 inch 40 watt black light fluorescent tubes in a standard fluorescent ceiling fixture

It is important to differentiate BLB tubes from regular black light of BL tubes, which lack a filter coating and exhibit a brighter blue colour as a consequence [4] [5]. These unfiltered are designed for applications such as “bug zapper” insect traps, where the emission of visible light does not impede the product’s performance. Due to any future countermeasure being a burning material ejected from the vehicle the use of a filter would be impossible as once the composition is ignited the temperature of combustion would destroy the outer filter rendering it useless. Therefore the same approach as BLB tubes cannot be used however the phosphor used to produce these emissions may be of interest for it UV production especially due to there being no concern with not wanting the visible portion of the spectrum so this would not be a limiting factor.

The phosphors utilized for near 368 to 371 nanometer emission peaks include europium-doped strontium fluoroborate ($SrB_2F_8:Eu^{2+}$) or europium-doped strontium borate ($SrB_2O_6:Eu^{2+}$). For a peak around 350 to 353 nanometers, lead-doped barium silicate ($BaSi_2O_5:Pb^{2+}$) is the typical choice as BLB lamps specifically, peak at 365nm [6]. From this there are no clear indications of a pattern of one single material that could be used to produce a UV output however there is clear indication that Europium and Strontium have a UV emission spectra at the high end of UV-A. Barium was also used as a base for doping and given both Strontium and Barium are alkaline metals this shows there may be a link between alkaline metals and UV production. However, this may not be the case and alkaline metal may just be good bases for doping with only three results a true conclusion cannot be drawn.

Incandescent black light lamps are crafted using an incandescent light bulb equipped with a filter coating that effectively absorbs the majority of visible light [7]. In certain scientific instruments, halogen lamps featuring fused quartz envelopes serve as cost-effective UV light

sources within the near UV range, spanning from 400 to 300nm. However, it is worth noting that a filament light bulb, due to its black-body spectrum, proves to be an inefficient UV source, emitting merely a fraction of a percent of its energy in the form of UV radiation [8]. This does therefor show that it is possible to produce UV radiation through black body emission although it is an inefficient method unless the temperature of the object is incredibly high which could possibly lead to damage to the vehicle the countermeasure is attached to. This method also has the downside of still producing a large amount of IR radiation alongside the UV when it would be preferred to keep the IR to a minimum.

For scientific applications, dedicated UV gas-discharge lamps containing distinct gases are used to generate UV radiation at specific spectral lines. Argon and deuterium arc lamps are commonly employed as reliable sources in UV spectroscopy equipment for chemical analysis. These lamps may be configured as windowless or equipped with various windows like magnesium fluoride [9], serving as crucial emitting sources in the realm of UV spectroscopy. Magnesium fluoride is used to due to its emission in the UV spectrum which is good for production of UV from MTV as it already contains both of those elements. It is possible therefor that by increasing the Magnesium Fluorine reaction the amount of UV produced would also increase. This could be achieved by replacing the Teflon with a material that is higher in Fluorine content to thereby increase the number of reactions taking place, producing more UV by making more Magnesium fluoride as a by product.

Moving from research concerning general UV production and into the more specialised field of UV pyrotechnics uncovered a paper investigating alternatives for Teflon [10]. This paper focused primarily on Caesium5-trifluoromethyletrazolate due to it having due to Caesium compounds containing lower crystal water content than lighter alkali and alkaline earth metals, which is key when working with magnesium due to its high reactivity with water typically rendering a composition inert. As can be seen in Figure 2 below KOCH's experiment shows the UV-VIS spectrum of the combustion of Magnesium with Caesium5-trifluoromethyletrazolate, the graph shows there are clear peaks in the UV wave bands produced by the formation of Magnesium Fluoride, Caesium and a single spike from Magnesium Oxide. This is beneficial as it backs ups the previous finding that Magnesium Fluoride is a good UV producer and that by increasing the number of these reactions, the amount of UV produced could be increased.

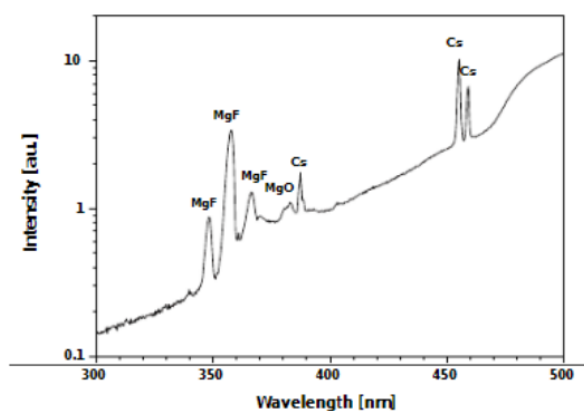


Figure 2 – Over view of UV-VIS spectrum of a strand of pyrolant [10]

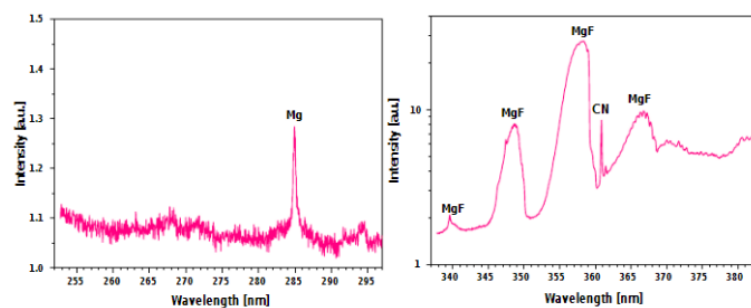


Figure 3 - Detail UV spectra of pyrolant [10]

The expanded UV-VIS spectra shown in Figure 3 give a clearer indication of where the peaks in the UV spectrum are, as well as showing additional peaks in a wider spectrum. A single peak produced by just Magnesium can be seen at 285nm which is at the lowest end of the wavelength ranges of concern, although useful to know that pure Magnesium decay can produce UV as it opens up the possibility to leave some of the Magnesium powder in MTV unreacted whilst having a non stoichiometric mixture.

Figure 4 shows the IR spectrum from this same Caesium, Magnesium combustion. Multiple peaks are clearly visible, which are caused by the Caesium and a few UV peaks present from Rubidium, which is believed to have been an impurity in the Caesium-5-trifluoromethyltetrazolate [10]. These IR peaks are unfortunate as it would be preferred to keep

the IR emissions as low as possible without adding any additional output that isn't already seen with MTV.

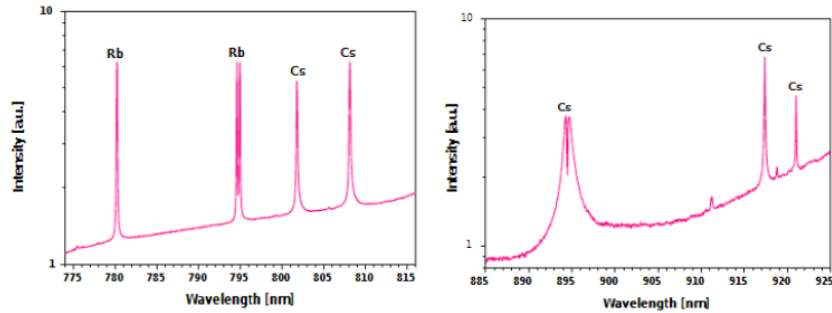


Figure 4 - Detail VIS spectra of pyrolant [10]

The Seventh International Pyrotechnics Seminar of 1980 contains a presentation by Henry Webster about the UV spectra of illuminating-type pyrotechnics [11]. His research focused on Standard Mk 45 Mod 0 Aircraft parachute flares containing a mixture of Magnesium and Sodium nitrate typically used by the navy for area illumination. These flares are significantly larger than conventional aircraft countermeasure flares measuring 11.4cm in diameter, 45.7cm in length and containing approximately 8.1kg of flare composition [12] compared to 24.64mm square end by 206mm length containing only 100g of composition [13]. For this reason any quantitative results from this tester would need to be considered with respect to the large size difference present however, any relativistic results are still applicable as they will irrespective of the size of the countermeasure.

20

The findings of the aforementioned paper show a grey body continuum overlap caused by reversed and broadened magnesium lines centred at 285nm along with sodium lines at 285 and 330nm seen in Figure 5, along with numerous atomic sodium and magnesium lines throughout the spectrum from 250-340nm.

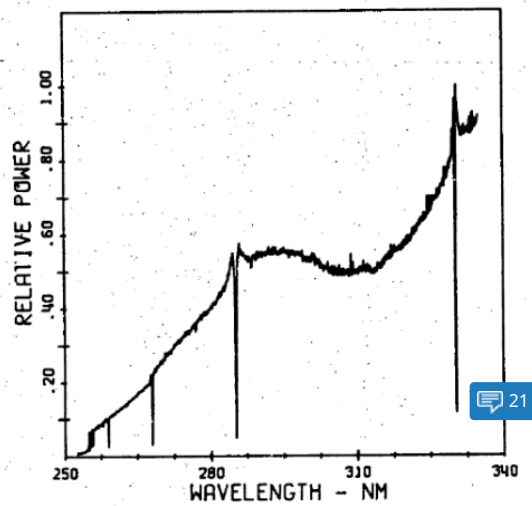


Figure 5 - Ultraviolet spectrum of MK45 Aircraft Parachute Flare [11]

All the atomic emission lines are present on Figure 5 for both Magnesium and Sodium as expected, although due to the figure scale it is hard to see the Magnesium lines aside from the 285.213nm line as this is a magnesium resonance line. When attempting to fit a blackbody curve to the results gathered, a curve corresponding to $2900^{\circ}K$ gives a reasonable fit in the region of 310-330nm seen in Figure 6 which gives a good indication of the flame temperature for this composition. For the region of 260-310nm the blackbody curve does not give a reasonable fit indicating that emission at these wavelengths is not simply from grey body emissions, but is being produced by the materials present.

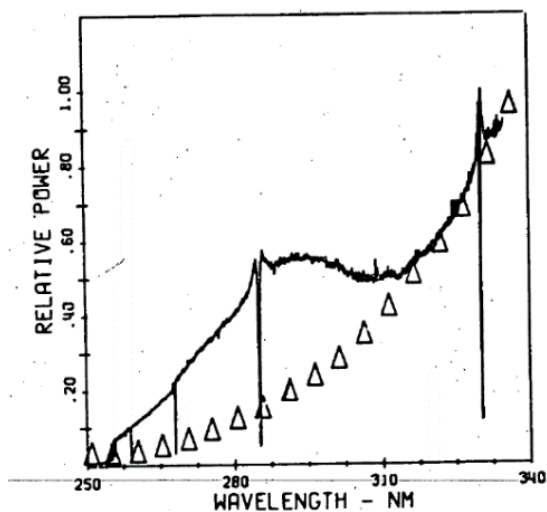


Figure 6 - Blackbody Curve Fit to MK45 Spectrum [11]

In conventional explosives Aluminium can be added in order to raise the reaction temperature, enhance the heat of detonation as well as create an incendiary effect [14] [15]. It would therefore stand to reason that Aluminium powder would have a similar effect on a pyrotechnic compositions as it would an explosive due to them both being energetics and the method energy release is the same. The primary difference between pyrotechnics and explosives is the rate of energy release. Explosives release all of their chemical potential very quickly producing a detonation whereas pyrotechnics release their energy more slowly normally referred to as deflagration [16].

Adding Aluminium to pyrotechnics has been previously studied as a way of using Magnalium alloy in place of regular Magnesium in an MTV composition [17]. Toan's research focused primarily on the burning rate and temperature of a Mg-Al reaction with Teflon over different ratios although they did also take a recording of the IR waveband which can be used to inform research. From the temperature data that was gathered, shown in Figure 7, it can be seen that at certain concentrations there is an increase in temperature over regular MTV which would normally only be $3338^{\circ}K$ [18] when Toan saw temperatures of nearly $4000^{\circ}K$.

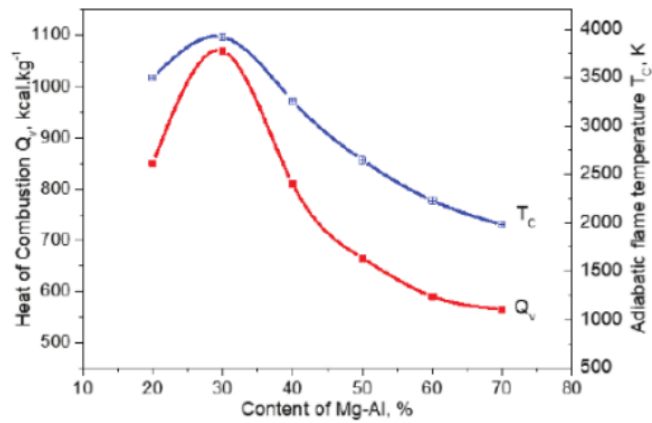


Figure 7 - Adiabatic Flame Temperature and Heat of Combustion of Mg-Al/PTFE/Viron Mixtures [17]

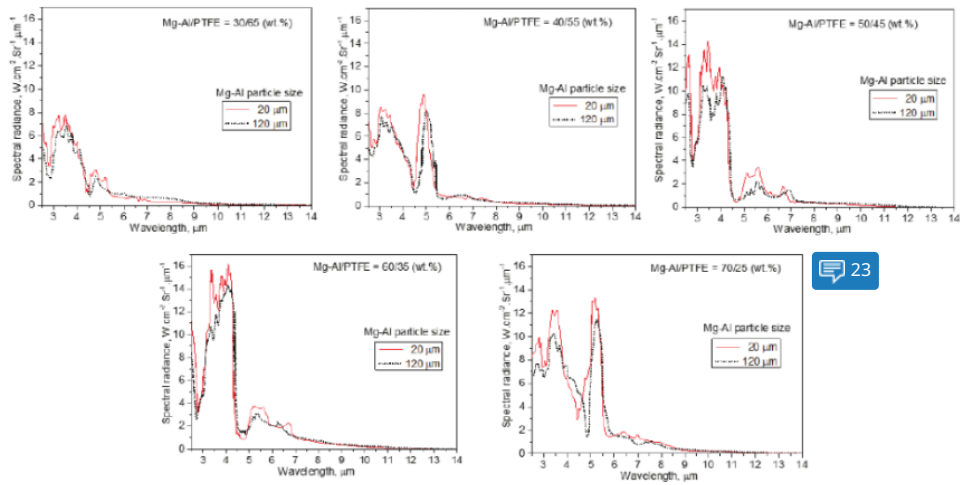


Figure 8 - Infrared Radiance Distribution of Several Mg-Al/PTFE/Viton Samples [17]

Figure 8 shows the IR distribution for the different samples that were tested. It shows that the higher the concentration of Mg-Al the higher the spectral radiance, which is what you would expect to see when comparing it with the flame temperatures for the same samples. At 30% ratio, which has the highest temperature on the spectral graph, the output curve has shifted to the left in accordance with a standard black body curve.

2.2 LITERATURE FINDINGS

From this literature review it is possible to narrow down the avenues of research that will be taken forward into the next stage. The materials that will be taken forward into the simulation stage will be Magnalium due to it showing an increase in the burn temperature over regular MTV which should increase the UV-VIS output through blackbody radiation.

Sodium Nitrate will also be investigated further as it has already shown an increase in the UV above what would be expected from a simple blackbody curve; although the data in this report was produced with older equipment that does not have the same accuracy as those found today. It may therefore be found to be a better UV producer than the initial findings would present.

Due to Strontium and Magnesium both being group two metals they will form bonds in the same way. Strontium fluoride and Magnesium fluoride are the two most prominent by products of this reaction due to the presence of fluorine in the Teflon. As there is no available data for whether or not Strontium fluoride produces UV, it is best to not make an assumption as to whether it does, as this would mean we would want to focus on the production of Magnesium fluoride instead. As Strontium fluoride has a lower enthalpy of formation than Magnesium fluoride does [19] [20], this would result in a larger amount of Strontium fluoride being created than Magnesium fluoride which is counter to what is desired. For this reason, compositions containing strontium will not be taken forward for more in-depth research.

Caesium 5-trifluoromethyletrazolate whilst showing promising outputs in the research already carried out, proved to be prohibitively expensive when looking into cost due to costing £301 per gram [21]. The average cost for the components of an aircraft counter measure is between £100 and £200, meaning a composition containing Caesium 5-trifluoromethyletrazolate would cost 3 times as much as a whole flare per gram. As established previously, there is 100g of composition in a flare about half of which would be the Caesium, resulting in an expected cost of 150 times the normal cost. This is unacceptable and would never be adopted by the defence sector; so although promising, further testing will not be conducted with this material.

Caesium also has the downside of being very reactive with water producing which could cause unintentional initiation of the magnesium due to the heat generated from the reaction. As MTV is already slightly hydro sensitive, it is undesirable to increase this property as it would lead to

an increased risk when used in a counter measure which will be exposed to the elements. Therefore, to get the spectra emissions expected of group one elements without increasing the risk of accidental initiation, Lithium was chosen as a substitute. Lithium has fewer spectral lines in the long wavelengths and more in the shorter wavelengths than caesium, as can be seen in Figure 9, so may not increase the IR output as much as Caesium would from the peaks seen in Figure 4.

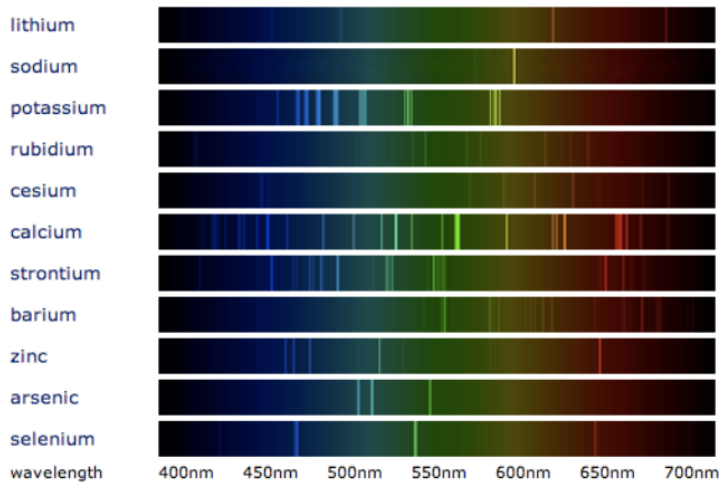


Figure 9 - Flame Emission Spectroscopy

Due to the presence of fluorine bonds being required, a material that contains both Lithium and Fluorine needed to be found which, unlike Caesium5-trifluoromethyletrazolate, is not prohibitively expensive. For these reasons Lithium Tetrafluoroaluminate was identified as it contains the same amount of Fluorine as Teflon so the Magnesium Fluorine reaction will be maintained whilst having the added benefits of both Lithium for altered IR output and Aluminium as identified previously to improve overall burn rate.

CHAPTER 3 - RESEARCH METHODOLOGY

3.1 RESEARCH PROCESS

The aim of this research is to produce the black body curves for the radiant intensity outputs from novel pyrotechnic compositions to aid in identifying potential compositions to take forward into small scale manufacture for real world testing. A simulated adiabatic flame temperature would allow for the production of these curves with a focus on comparison to a known composition to ensure if the simulation has the accuracy required to truly estimate real world events. The research will require a multistage approach whereby a simulation will first need to be run in order to produce the estimated adiabatic flame temperature, then mathematical calculations will need to be run for different wave lengths in order to produce the black body curve needed for comparison. Lastly any additional observations can be made using the known spectral outputs of the by-products to determine if an increase in UV has in fact happened.

3.2 DATA COLLECTION

Data collection will be a simple process as the majority of the data produced will be done by the simulation software, which will produce the adiabatic flame temperature along with the expected products of combustion. For comparative data that will be used to draw conclusions a combination of methods will be used; firstly, a mathematical calculation will allow for the estimated radiant intensity of different wave lengths for each composition to be produced. Excel will be used or this as a table can be produced containing a number of wave lengths across the electromagnetic spectrum with the radiant intensity for each calculated using Planck's Law of black-body radiation. The Excel graphing function can then be used to produce a visual representation of the black body curve. Not all wavelengths have to be calculated because blackbody curves have a general shape for which Excel can interpret the intermediary values that were not manually calculated. The overall energy produced by the system will be calculated using the Stefan-Boltzmann Law and peak wavelengths given by Wein's displacement law.



The second method of data gathering is interpretation of the expected products of combustion. Certain materials have known spectral outputs, so by analysing these it is possible to predict where peaks would appear in the emission spectra outside of the normal blackbody curve indicating areas of higher output.

CHAPTER 4 - DESIGN & IMPLEMENTATION

4.1 DESIGN

In order to produce the adiabatic flame temperature and the expected combustion products the thermochemical modelling software known as EXPLO5 will be used. EXPLO5 is a thermochemical software application designed to accurately predict the detonation properties and combustion characteristics of high explosives and propellants [22]. These properties include: the composition of detonation products, detonation velocity, pressure, temperature, heat, and more. The software is instrumental in the synthesis, formulation, and numerical modelling of energetic materials. Detonation parameter calculations in EXPLO5 are grounded in a chemical equilibrium, steady-state detonation model [23]. The equilibrium composition of detonation products is determined using a free energy minimization technique. The program utilizes the Becker-Kistiakowsky-Wilson (BKW) equation of state for gaseous detonation products [24] and either the Murnaghan or Cowan-Fickett's equation of state [25] for solid products.

EXPLO5 facilitates the calculation of chemical equilibrium composition and thermodynamic parameters along shock adiabates of detonation products, as well as at the CJ state and along the expansion isentrope. Its user-friendly interface begins with a single edit window, providing an intuitive experience for users. The program employs a non-linear curve fitting subroutine based on the Jones-Wilkins-Lee (JWL) model [26] to fit relative volume-pressure data along the expansion isentrope, enabling the calculation of detonation energy available for mechanical work. For combustion performance calculations under constant pressure or volume conditions, EXPLO5 utilizes the ideal gas or virial equation of state. The virial coefficients of individual gaseous species are computed from intermolecular potential equations.

4.2 IMPLEMENTATION

The simulation will be configured to produce a propellant simulation, as this is the closest to a pyrotechnic composition due to both a pyrotechnic and a propellant are a deflagration of energetic materials made up of semi homogenous mix of materials suspended in a binder [27]. In order to set up a simulation three things are required: the formulation of your material in terms of its elemental makeup, the density of the material in grams per cubic centimetre and the heat of formation in KJ/mol. This makes it easy to produce simulations for unknown materials as the small number of requirements makes it possible to add more materials to the simulation that the software may not already have stored.

The compositions that were simulated can be seen below in Table 1, for most of these materials the properties were pre-loaded into the software as it pulls from the Fraunhofer-Institut für Chemische Technologie (ICT)-database of thermochemical values [28]. The only material that could not be found in this database was Lithium Tetrafluoroaluminate for which values were gathered from PyroMat and entered manually. PYroMat is a Python package for conveniently retrieving the thermodynamic properties of substances that is produced and maintained by a team at Penn State, Altoona [29].

Table 1 - Compositions to be tested with ratios

Materials for composition A	Ratio by weight
Magnalium	5
Teflon	4.5
Viton A	0.5
Materials for composition B	
Magnesium	5
Lithium Tetrafluoroaluminate	4.5
Viton A	0.5
Materials for composition C	
Magnesium	5
Sodium Nitrate	4.5
Viton A	0.5
Materials for composition D	
Magnesium	5
Teflon	4.5
Viton A	0.5

The ratios for the above listed compositions were chosen by using an existing known composition which is also being tested, listed above as composition D. This is a known MTV composition that has documented data allowing for a comparison between the simulated results and real word testing. A difference between the simulated and real world data can be considered the factor of error; however it can also be used to produce a factor of correction which is then applied to all of the other simulated results to bring them more in line with what should happen

in real world testing. This is using the assumption that software will treat all of the compositions with the same errors occurring which cannot be guaranteed or confirmed without real testing of all the compositions.

CHAPTER 5 – TESTING AND EVALUATION

All the simulations were set up and run as described in the design implementation section above, taking approximately 3 hours to run all the simulations using a 32 core computing cluster. The full results produced by the software can be seen at the end of this report in an appendix corresponding to the composition name, for example composition A is appendix A. The remainder of this section will be talking about the overall results of these simulations and the other calculations that were conducted with the simulation results.

As discussed previously, composition D is being used for all comparisons due to being the real world benchmark. For this reason, it will be the first set of results that are investigated to see if we have an error factor that can be applied to the other results as a correction factor. The adiabatic temperature of composition D was simulated as 2605 degrees kelvin, however real world testing for this composition places the temperature at approximately 2800 kelvin. This would produce a correction factor of $\frac{2800}{2600} = 1.075$ which can then be applied to all other temperature results for the other compositions in an attempt to more accurately match the simulated results with what would be produced in real world testing.

In order to calculate the blackbody curves for each composition the Stefan-Boltzmann law will be used. The Stefan-Boltzmann law also known as Stefan's law, describes the intensity of the thermal radiation emitted by matter in terms of that matter's temperature and is given by

$$P = \sigma * A * T^4$$

Where:

The equation is typically rearranged to produce power over area which is seen on the axis of blackbody graphs and will be what is used for all calculations in this paper.

For composition A, where the magnesium was swapped out for Magnalium, the predicted adiabatic flame temperature from simulation was 1996°K which then will become 2145.7°K

once the factor of correction that was previously calculated is applied. The overall spectral radiance can now be calculated with the Stefan-Boltzmann law giving an estimated radiance of $\sigma * 2145.7^2 = 1201952 \text{ W/m}^2$, this will be used later on to compare all the compositions. The blackbody curve produced by this temperature can be seen below in Figure 10 along with the data used to produce this graph in Table 2 as an example for how all the calculations are being handled.

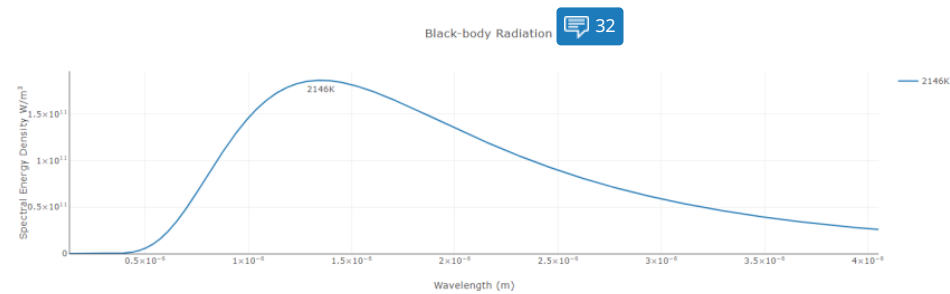


Figure 10 - Blackbody Curve for Composition A

Table 2 - Calculated blackbody values for composition A through Planck's Law

Temperature (K)	2145.7
Wave length (nm)	Radiance (W/m^3)
200	3503
300	9.64E+06
400	6.47E+08
500	5.71E+09
600	2.17E+10
700	4.99E+10
800	8.36E+10
900	1.18E+11
1000	1.46E+11
1500	1.81E+11
2000	1.35E+11
2500	8.95E+10
3000	5.82E+10
3500	3.91E+10

4000	2.67E+10
------	----------

From the graph it can be seen that an output of $1.86 \times 10^{11} W/m^3$, with a peak wavelength of approximately $1.35 \times 10^{-6} m$ or $1.35 \mu m$. This wave length falls into the IR spectrum which is not what is desired although is expected due to a temperature of 4000 Kelvin being needed to produce a peak wavelength in the UV range. For the UV range of interest the radiance was $17.4992 W/m^2/sr$, this output is low compared to the overall output of the composition indicating that there is very little overall UV produced simply by the blackbody radiation.

Looking at the estimated solid products of the combustion allows for assumptions of areas where there will be an increase in emissions above the blackbody curve. For this composition three solid products are produced: Magnesium Fluoride, Aluminium Fluoride and Aluminium oxide. The Magnesium Fluoride will produce known peaks as identified in the earlier literature research, there is no known UV or visible spectrum output for Aluminium Fluoride however Aluminium oxide is known to emit at wavelengths between 190-280nm with a peak at 205nm [30].

For composition B, where the Teflon was swapped out for Lithium Tetrafluoroaluminate the predicted adiabatic flame temperature from simulation was $2296.6^\circ K$ which then will become $2468.8^\circ K$ once the factor of correction that was previously calculated is applied. The overall spectral radiance can now be calculated with the Stefan-Boltzmann law giving an estimated radiance of $\sigma * 2468.8^2 = 2106468 W/m^2$. The blackbody curve produced by this temperature can be seen below in Figure 11.

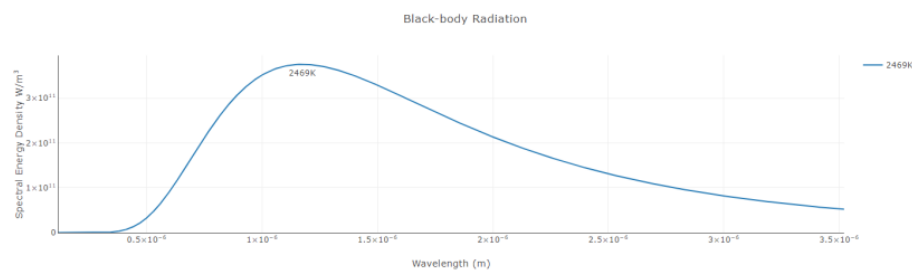


Figure 11 - Blackbody Curve for Composition B

From the graph it can be seen that an output of $3.76 \times 10^{11} \text{ W/m}^3$, with a peak wavelength of approximately $1.17 \times 10^{-6} \text{ m}$ or $1.17 \mu\text{m}$. This wave length falls into the IR spectrum although as expected has moved closer to the UV range of interest due to the higher temperature. For the UV range of interest the radiance was $184.73 \text{ W/m}^2/\text{sr}$, this output is low compared to the overall output of the composition, but is increased compared to composition A so does show an improvement.

Looking at the estimated solid products of the combustion allows for assumptions of areas where there will be an increase in emissions above the blackbody curve. For this composition five solid products are produced: Magnesium Fluoride, Magnesium oxide, Lithium Fluoride, magnesium aluminate and Magnesium Carbonate. The Magnesium Fluoride will produce known peaks as identified in the earlier literature research along with the Magnesium Oxide. The Magnesium Aluminate has been shown to have a small amount of additional emissions at the top end of the UV waveband along with strong emissions in the visible [31]. No relevant information could be found for the emissions of Lithium fluoride or Magnesium Carbonate however the presents of both magnesium Carbonate and Magnesium Aluminate indicates that less Magnesium Fluorine reactions took place which will reduce the peak expected at those wavelengths.

For composition, C where the Teflon was swapped out for Sodium Nitrate, the predicted adiabatic flame temperature from simulation was 3269.4°K which then will become 3514.6°K once the factor of correction that was previously calculated is applied. The overall spectral radiance can now be calculated with the Stefan-Boltzmann law giving an estimated radiance of $\sigma * 3514.6^2 = 86519668 \text{ W/m}^2$. The blackbody curve produced by this temperature can be seen below in Figure 12.

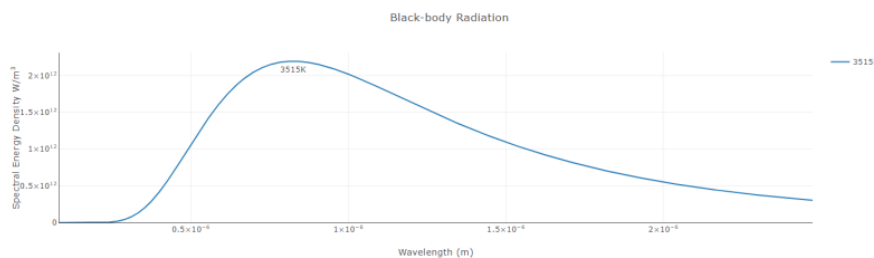


Figure 12 - Blackbody Curve for Composition C

From the graph it can be seen that an output of $2.20 \times 10^{12} W/m^3$, with a peak wavelength of approximately $8.22 \times 10^{-7} m$ or $822nm$. This wave length falls just outside of the visible spectrum and into the IR range. For the UV range of interest the radiance was $21411.1 W/m^2 /sr$, this output significantly higher than the other compositions showing a large increase in the overall UV production.

Looking at the estimated solid products of the combustion allows for assumptions of areas where there will be an increase in emissions above the blackbody curve. For this composition five solid products are produced: Magnesium Oxide, Sodium Fluoride, Sodium Oxide, Magnesium Carbonate and Magnesium Hydrogen peroxide. From this it is possible to determine that the Magnesium Oxide peak at around $385nm$ as seen in Figure 2 of the literature review. There is no adequate data available for UV-VIS emissions of any of the other products. Compared to the other compositions, this composition is completely lacking the Magnesium Fluorine reaction so will not have any additional peak for these regions. 35

Lastly is Composition D, which is the know composition and is to be used to compare all other compositions to the predicted adiabatic flame temperature from simulation was $2605^\circ K$ however the value $2800^\circ K$ will be used as discussed earlier in this report due to being a known real world value. The overall spectral radiance can now be calculated with the Stefan-Boltzmann law giving an estimated radiance of $\sigma * 2800^2 = 3485325 W/m^2$. The blackbody curve produced by this temperature can be seen below in Figure 13.

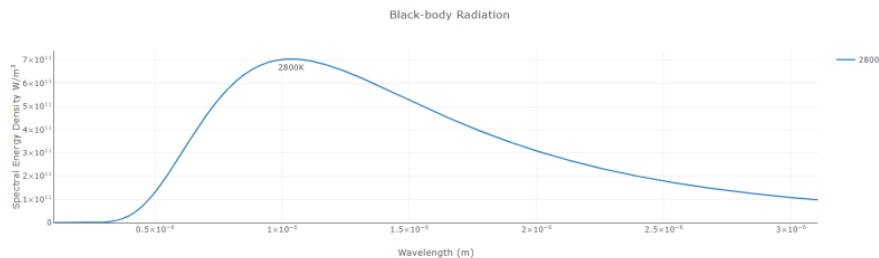


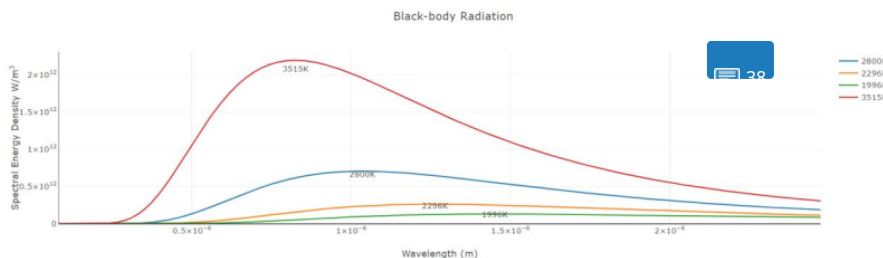
Figure 13 - Blackbody Curve for Composition D

From the graph it can be seen that an output of $7.04 \times 10^{11} W/m^3$, with a peak wavelength of approximately $1.03 \times 10^{-6} m$ or $1\mu m$. This wave length falls just outside of the visible spectrum and into the IR range. For the UV range of interest the radiance was

1201.81W/m²/sr, this output is higher than most of the other compositions indicating that the other compositions have a comparatively lower UV production except for composition C which shows a significantly higher output.

Looking at the estimated solid products of the combustion allows for assumptions of areas where there will be an increase in emissions above the blackbody curve. For this composition, four solid products are produced; Magnesium Oxide, Magnesium Fluoride, Magnesium Carbonate and Magnesium Hydrogen peroxide. From this, it is possible to determine that the Magnesium Oxide peak along with the Magnesium Fluoride peak will be visible. There is no adequate data available for UV-VIS emissions of any of the other products as previously mentioned.

Figure 13 shows a graph with all four of the tested composition's predicted blackbody curves. From this it is possible to clearly see the increase in overall output of composition C (Red) against the baseline composition D (Blue). Not only is the overall energy higher but the peak is shifted to the left which indicates a shorter waveband. From this, as well as the numerical calculations it can be inferred that composition C shows the most promise to achieve the desired outcome of increasing the UV and visible wave bands. The graph does however also show an increase in IR when compared to the other compositions. This is due to the overall emissions coming from a blackbody curve where emission is distributed throughout, therefore an increase in IR emissions is unavoidable.



CHAPTER 6 - CONCLUSIONS AND RECOMMENDATIONS

6.1 SUMMARY

In summary, this report has laid out the reasons why research into this field is key to increasing the protection of military vehicles and assets which are vital in the protection of personnel.

The research and literature review section has described how UV is currently produced in a commercial environment, as well as current research uses for UV such as arc lamps. Existing research that may be relevant to the specific subject of UV pyrotechnics was also discussed identifying a number of papers that, although do not directly discuss the topic, do contain useful information that allowed for an informed decision as to what was needed to be taken forward to the simulation and testing stage. The main materials that stood out from this literature search were Magnesium and Sodium nitrate, with Caesium 5-trifluoromethyltetrazolate also being identified, but determined to be too dangerous to continue research with. However, this paper along with the research into the effects of aluminium provided the information needed to identify Lithium Tetrafluoroaluminate as a third possible material.

These three materials were then taken forward into the simulation stage where the material properties were identified in order to add them to a simulation along with a base line, known composition both for comparison of results and to provide a framework for the ratios of each composition. The simulation was then carried out with the data from each being recorded and labelled in accordance with which composition it was. These simulated results then allowed for the mathematical calculations of total radiance, blackbody curves and peak wavelength of each composition which would then could be used to compare them all to the base line, and identify if any of the new compositions met the research aim of increasing UV and visible output.

6.2 CONCLUSION

In conclusion only one of the new compositions showed the possibility of producing the required increased UV output. Compositions A and B, although showing promise from initial literature reviews did not produce the expected increase in the UV output. It should however be considered that because these results were based on the blackbody curves for each composition they are unlikely to be a true representation of the actual spectral output of the compositions. This is because no material is a true perfect black body source and will always have areas that deviate from the curve either due to the materials being used or from atmospheric conditions such as not being at exactly 1 atmosphere of pressure.

Similar to blackbody predictions not being able to be perfect, neither are the simulations that were run. These predictions assume that everything is taking place at 1 atmosphere which is

unlikely to happen, as while the compositions burn in confinement the pressure will increase changing the prediction. Also, the simulation software was designed for propellants and explosives, while pyrotechnics fall slightly outside of that, although the mechanisms for pyrotechnics and propellants are roughly the same they aren't identical. It is for this reason the flame temperatures of the aluminium containing compositions may have been lower than the regular MTV, when in theory they should have presented a much closer if not higher temperature. In a regular propellant, aluminium is added to alter the burn rate in small amounts, for pyrotechnics the aluminium acts as a fuel similar to a thermite reaction which the software is not designed to calculate. This is likely lead to an effort in simulations reducing the overall temperature outputs.

Overall, the testing and predictions in this report provide a good fundamental knowledge of the likely effects of the compositions; however without further testing, including real world tests to act as validation of these compositions, the results cannot be guaranteed to be truly accurate.

6.3 RECOMMENDATIONS FOR FURTHER RESEARCH

It would be the recommendation of this report that the research be continued with the identified compositions. This should be done as both a way to validate the simulations carried out as if validated as accurate they can be used to future research to cut down on the need for potentially dangerous real world testing. This would also help to determine if the identified improved composition would in fact be better than current MTV or if it is simply just a case of the predicted curve being what is needed and not the actually output when material and atmospheric effects come into play.

The recommended next step in research would be to produce a series of small 10 gram batches of the compositions for the purposes of small scale hazard testing. This hazard testing should be done before any other testing such as burn testing takes place due to the unknown nature of the compositions. Although they are all based off an existing composition in terms of the materials' ratios, there is no understanding of what effects these material changes may have on the sensitivity of the composition. Therefore to ensure the safety of any operators working with the compositions it is important to have a full knowledge of what the new sensitivity of the material in accordance with the Energetic Materials Testing Assessment Policy Manual of Tests (EMTAP).

Both a risk assessment and method statement for this continuation of work have since been produced, as well as the procedures needed to not only produce small samples of the material for EMTAP testing, but also how to do so safely taking into consideration all the risks that may be present in an energetics task with unknown variables.

CHAPTER 7 – REFLECTIONS

The aim of this report was to create a better understanding of the method of UV production in standard MTV and make recommendations as what material substitutions may be able to be used in order to increase this UV output along with the visible spectrum output. With this aim in mind the report was a success, ultimately an understanding of what UV is and how it is produced by MTV was developed by looking into the previous work conducted, and using a wide array of sources to draw conclusions as to what properties of MTV were effecting the UV output.

For the suggestion of materials for altered compositions, a list of three viable compositions was produced and investigated in accordance with the objectives, with one showing promise and a recommendation to carry out further testing to validate this work and the methods used within it.

Issues did occur during the course of this research, namely limitations from a safety perspective that limited testing to purely simulations. This was caused by external factors and could have been overcome if more time were allowed and will not stop any future research.. It is evident from the report that an alternative method was found and the limitation of no physical testing was overcome with the use of accredited simulations along with renowned physics calculations to form predictions of what any real world testing results would have been. These methods allowed for the greatest level of accuracy possible outside of real testing as they have all been used for many years, resulting in them being peer reviewed and industrially used without issue.

Through the method statement and risk assessment the original direction of this report can be seen, in terms of getting real world testing conducted. Overall without this testing the aim and objectives have been met as best as possible. Better results would have been recorded with the

use of real world testing; therefore further testing has been recommended and for the project not to end at this stage.  40

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Appendix A:

COMPOSITION_A

Reference state = Reactants

$$H(R) = H - (-8.63), E(R) = E - (-28.95), S(R) = S - (0.00)$$

1.)

THERMODYNAMICS

#####

P [atm]: 1.000000e+000
V [cc/g]: 8.3682205e+002
T [K]: 2.9815000e+002
H(R) [cal/g]: -5.0568450e+001
E(R) [cal/g]: -5.0516016e+001
S(R) [cal/(K g)]: 1.6271605e+000
V gas [cc/g]: 8.3681865e+002
Speed of sound [m/s]: 3.4245162e+002
Cv [cal/(K g)]: 1.7804991e-001
Cp [cal/(K g)]: 2.4628760e-001
Alpha : 2.6161191e+000
Beta : 2.6145323e+000
Kappa : 1.3830845e+000

TRANSPORT

#####

Shear viscosity [Pa s]: 2.1946388e-005
Kinematic viscosity [m^2/s]: 1.8365221e-005
Thermal conductivity [W/(m K)]: 2.3915444e-002
Thermal diffusivity [m^2/s]: 1.9421257e-005

Electrical conductivity [1/(Ohm m)]: 3.3260293e-021
Gas effective diffusion constant [m^2/s]: 2.2349271e-005
Gas relative dielectric constant: 1.0000014e+000

PRODUCTS

#####

Name	Phase	[mol/kg]	[mol/mol]	[kg/kg]	[mol frac]
n2	gas	2.709e+001	7.839e-001	7.589e-001	7.888e-001
o2	gas	7.021e+000	2.031e-001	2.246e-001	2.044e-001
co2	gas	9.335e-002	2.701e-003	4.108e-003	2.718e-003
h2o	gas	4.677e-003	1.353e-004	8.426e-005	1.362e-004
no2	gas	6.560e-009	1.898e-010	3.018e-010	1.910e-010
hf	gas	2.116e-010	6.124e-012	4.234e-012	6.163e-012
*al2o3	solid	7.104e-002	2.056e-003	7.243e-003	2.069e-003
*alf3	solid	5.157e-002	1.492e-003	4.331e-003	1.502e-003
*mgf2	solid1	1.131e-002	3.274e-004	7.049e-004	3.295e-004

Total Gas 3.421e+001 9.899e-001 9.877e-001 9.961e-001
Total Condensed 1.339e-001 3.875e-003 1.228e-002 3.900e-003

Adiabatic flame temperature (constant pressure): T [K]: 1.9964187e+003

PRODUCTS at fixed h 0, p 1:

#####

Name	Phase	[mol/kg]	[mol/mol]	[kg/kg]	[mol frac]
al	gas	1.309e+001	5.313e-001	3.531e-001	4.315e-001
alf3	gas	5.862e+000	2.380e-001	4.922e-001	1.933e-001
mg	gas	1.131e+000	4.594e-002	2.750e-002	3.731e-002
h2	gas	2.597e-001	1.054e-002	5.236e-004	8.564e-003

h	gas	1.282e-001	5.203e-003	1.292e-004	4.226e-003
hf	gas	1.241e-001	5.040e-003	2.484e-003	4.094e-003
c2h2	gas	6.895e-002	2.800e-003	1.795e-003	2.274e-003
hp	gas	2.583e-002	1.049e-003	1.581e-004	8.518e-004
fm	gas	2.583e-002	1.049e-003	3.587e-004	8.518e-004
f	gas	2.064e-004	8.381e-006	3.922e-006	6.807e-006
c	gas	1.009e-004	4.097e-006	1.212e-006	3.327e-006
ch4	gas	7.407e-007	3.007e-008	1.188e-008	2.442e-008
c2h4	gas	1.745e-007	7.083e-009	4.894e-009	5.752e-009

*c graphite 9.197e+000 3.734e-001 1.105e-001 3.033e-001

*al liquid 4.180e-001 1.697e-002 1.128e-002 1.378e-002

Total Gas 2.071e+001 8.409e-001 8.783e-001 6.829e-001

Total Condensed 9.615e+000 3.904e-001 1.217e-001 3.171e-001

Appendix B:

COMPOSITION_B

Reference state = Reactants

$$H(R) = H - (-16.92), E(R) = E - (-37.23), S(R) = S - (0.00)$$

1.)

THERMODYNAMICS

#####

P [atm]: 1.000000e+000
V [cc/g]: 8.3633088e+002
T [K]: 2.9815000e+002
H(R) [cal/g]: -3.8292857e+001
E(R) [cal/g]: -3.8228497e+001
S(R) [cal/(K g)]: 1.6256827e+000
V gas [cc/g]: 8.3632662e+002
Speed of sound [m/s]: 3.4219017e+002
Cv [cal/(K g)]: 1.7855677e-001
Cp [cal/(K g)]: 2.4675531e-001
Alpha : 2.6250993e+000
Beta : 2.6234911e+000
Kappa : 1.3817845e+000

TRANSPORT

#####

Shear viscosity [Pa s]: 2.1946741e-005
Kinematic viscosity [m^2/s]: 1.8354737e-005
Thermal conductivity [W/(m K)]: 2.3946411e-002
Thermal diffusivity [m^2/s]: 1.9398153e-005
Electrical conductivity [1/(Ohm m)]: 1.0467571e-014
Gas effective diffusion constant [m^2/s]: 2.2378277e-005

Gas relative dielectric constant: 1.0000000e+000

PRODUCTS

#####

Name	Phase	[mol/kg]	[mol/mol]	[kg/kg]	[mol frac]
n2	gas	2.709e+001	7.835e-001	7.589e-001	7.863e-001
o2	gas	7.098e+000	2.053e-001	2.271e-001	2.060e-001
h2o	gas	1.657e-005	4.791e-007	2.984e-007	4.809e-007
no2	gas	6.635e-009	1.919e-010	3.052e-010	1.926e-010
co2	gas	1.508e-010	4.360e-012	6.635e-012	4.376e-012
*mgo	solid	1.268e-001	3.667e-003	5.110e-003	3.680e-003
*mgf2	solid1	6.327e-002	1.830e-003	3.942e-003	1.837e-003
*lif	solid	3.639e-002	1.052e-003	9.440e-004	1.056e-003
*mgal2o4	solid	1.820e-002	5.262e-004	2.589e-003	5.282e-004
*mgco3	solid	1.336e-002	3.865e-004	1.127e-003	3.879e-004
Total Gas		3.419e+001	9.888e-001	9.860e-001	9.924e-001
Total Condensed		2.627e-001	7.597e-003	1.398e-002	7.625e-003

Adiabatic flame T (constant pressure): T [K]: 2.2966348e+003

Appendix C:
COMPOSITION_C

Reference state = Reactants

$H(R) = H - (-6.16)$, $E(R) = E - (-26.48)$, $S(R) = S - (0.00)$

1.)

THERMODYNAMICS

#####

P [atm]: 1.000000e+000
V [cc/g]: 8.3834451e+002
T [K]: 2.9815000e+002
H(R) [cal/g]: -3.2257875e+001
E(R) [cal/g]: -3.2242285e+001
S(R) [cal/(K g)]: 1.6292795e+000
V gas [cc/g]: 8.3834101e+002
Speed of sound [m/s]: 3.4277316e+002
Cv [cal/(K g)]: 1.7834063e-001
Cp [cal/(K g)]: 2.4670345e-001
Alpha : 2.6156278e+000
Beta : 2.6140220e+000
Kappa : 1.3831666e+000

TRANSPORT

#####

Shear viscosity [Pa s]: 2.1952127e-005
Kinematic viscosity [m^2/s]: 1.8403445e-005
Thermal conductivity [W/(m K)]: 2.3948111e-002
Thermal diffusivity [m^2/s]: 1.9450326e-005

Electrical conductivity [1/(Ohm m)]: 7.9306993e-013
Gas effective diffusion constant [m^2/s]: 2.2379927e-005
Gas relative dielectric constant: 1.0000000e+000

PRODUCTS

#####

Name	Phase	[mol/kg]	[mol/mol]	[kg/kg]	[mol frac]
n2	gas	2.711e+001	7.839e-001	7.595e-001	7.852e-001
o2	gas	7.157e+000	2.069e-001	2.290e-001	2.073e-001
h2o	gas	1.660e-005	4.800e-007	2.991e-007	4.808e-007
no2	gas	6.685e-009	1.933e-010	3.075e-010	1.936e-010
co2	gas	1.511e-010	4.368e-012	6.649e-012	4.376e-012
*mgo	solid	2.083e-001	6.021e-003	8.394e-003	6.032e-003
*naf	solid	1.737e-002	5.023e-004	7.295e-004	5.031e-004
*na2o	solid	1.484e-002	4.292e-004	9.200e-004	4.299e-004
*mgco3	solid	1.336e-002	3.864e-004	1.127e-003	3.870e-004
*mgh2o2	solid	4.661e-003	1.348e-004	2.718e-004	1.350e-004
Total Gas		3.427e+001	9.908e-001	9.886e-001	9.925e-001
Total Condensed		2.585e-001	7.474e-003	1.144e-002	7.487e-003

Adiabatic flame T (constant pressure): T [K]: 3.2694604e+003

PRODUCTS at fixed h 0, p 1:

#####

Name	Phase	[mol/kg]	[mol/mol]	[kg/kg]	[mol frac]
mg	gas	1.196e+001	4.354e-001	2.907e-001	3.486e-001
na	gas	4.706e+000	1.713e-001	1.082e-001	1.372e-001
n2	gas	2.264e+000	8.242e-002	6.342e-002	6.598e-002

co	gas	1.132e+000	4.123e-002	3.172e-002	3.300e-002
o	gas	8.929e-001	3.251e-002	1.429e-002	2.602e-002
hf	gas	5.434e-001	1.978e-002	1.087e-002	1.584e-002
f	gas	5.133e-001	1.868e-002	9.751e-003	1.496e-002
o2	gas	4.983e-001	1.814e-002	1.595e-002	1.452e-002
hp	gas	3.622e-001	1.318e-002	3.651e-004	1.055e-002
fm	gas	3.605e-001	1.312e-002	6.849e-003	1.051e-002
co2	gas	2.039e-001	7.423e-003	8.974e-003	5.942e-003
no	gas	1.777e-001	6.468e-003	5.331e-003	5.177e-003
h	gas	2.686e-002	9.778e-004	2.707e-005	7.827e-004
ohm	gas	1.694e-003	6.169e-005	2.882e-005	4.938e-005
n	gas	4.799e-004	1.747e-005	6.721e-006	1.398e-005
h2o	gas	3.940e-004	1.434e-005	7.097e-006	1.148e-005
h2	gas	2.746e-004	9.998e-006	5.536e-007	8.004e-006
no2	gas	2.224e-005	8.096e-007	1.023e-006	6.481e-007
cfo	gas	4.185e-006	1.523e-007	1.967e-007	1.220e-007
n2o	gas	3.111e-006	1.133e-007	1.369e-007	9.067e-008
f2	gas	9.554e-007	3.478e-008	3.630e-008	2.784e-008
o3	gas	1.680e-007	6.117e-009	8.065e-009	4.897e-009
c	gas	2.424e-009	8.823e-011	2.911e-011	7.063e-011
hcn	gas	1.397e-009	5.084e-011	3.774e-011	4.070e-011

*mgo	liquid	1.051e+001	3.826e-001	4.236e-001	3.063e-001
*mgf2	liquid	1.601e-001	5.828e-003	9.973e-003	4.665e-003

Total Gas		2.364e+001	8.608e-001	5.665e-001	6.891e-001
-----------	--	------------	------------	------------	------------

Total Condensed		1.067e+001	3.884e-001	4.335e-001	3.109e-001
-----------------	--	------------	------------	------------	------------

Appendix D:

Composition D

Reference state = Reactants

$$H(R) = H - (-8.63), E(R) = E - (-28.95), S(R) = S - (0.00)$$

1.)

THERMODYNAMICS

#####

P [atm]: 1.000000e+000
V [cc/g]: 8.353534e+002
T [K]: 2.981500e+002
H(R) [cal/g]: -4.676024e+001
E(R) [cal/g]: -4.667221e+001
S(R) [cal/(K g)]: 1.623946e+000
V gas [cc/g]: 8.353484e+002
Speed of sound [m/s]: 3.419434e+002
Cv [cal/(K g)]: 1.785250e-001
Cp [cal/(K g)]: 2.466438e-001
Alpha : 2.627705e+000
Beta : 2.626094e+000
Kappa : 1.381407e+000

TRANSPORT

#####

Shear viscosity [Pa s]: 2.194263e-005
Kinematic viscosity [m^2/s]: 1.832985e-005
Thermal conductivity [W/(m K)]: 2.394512e-002
Thermal diffusivity [m^2/s]: 1.938319e-005
Electrical conductivity [1/(Ohm m)]: 2.490090e-013
Gas effective diffusion constant [m^2/s]: 2.237702e-005
Gas relative dielectric constant: 1.000000e+000

PRODUCTS

#####

Name	Phase	[mol/kg]	[mol/mol]	[kg/kg]	[mol frac]
n2	gas	2.709e+001	7.834e-001	7.589e-001	7.881e-001
o2	gas	7.058e+000	2.041e-001	2.259e-001	2.053e-001
h2o	gas	1.656e-005	4.788e-007	2.983e-007	4.816e-007
no2	gas	6.601e-009	1.909e-010	3.037e-010	1.920e-010
co2	gas	1.508e-010	4.361e-012	6.637e-012	4.387e-012
*mgco3	solid	9.335e-002	2.700e-003	7.871e-003	2.716e-003
*mgf2	solid1	8.867e-002	2.564e-003	5.525e-003	2.580e-003
*mgo	solid	3.960e-002	1.145e-003	1.596e-003	1.152e-003
*mgh2o2	solid	4.661e-003	1.348e-004	2.718e-004	1.356e-004
Total Gas		3.415e+001	9.875e-001	9.847e-001	9.934e-001
Total Condensed		2.263e-001	6.544e-003	1.526e-002	6.583e-003

Adiabatic flame temperature (constant pressure): T [K]: 2.6051985e+003F

The effects of chemical additives on the ultra violet output of MTV

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Please ask Jenni Steen for your marking sheet for feedback.

46/100

PAGE 1

Text Comment. Second marker:

PAGE 2

PAGE 3



Comment 1

MTV??? acronyms must be explained when used first time in the text



Comment 2

This abstract sounds more like the introduction. In a correctly written abstract you are expected to tell the reader what were your overall aims and objectives, what methods were used and what was found followed by a short conclusion or recommendations.

PAGE 4



Comment 3

page numbers are missing



Comment 4

these are called appendix (appendices, plural) not abstracts

PAGE 5

PAGE 6

Text Comment. ???



Comment 5

What is UC?



Comment 6

this sentence is not clear



Comment 7

Good statement of the problem. You have started with a broad argument which should be refined to more specific items. This step is missing in your introduction. More background information is needed.

Importance of blackbody radiation in this project should be introduced here (definition, picture, etc).



Comment 8

effect



Comment 9

what are these laws?



Comment 10

Is this a part of the literature review? The UV properties of MTV should be well analysed and described already. Is this step going to contribute anything new?



Comment 11

How are you going to achieve this?



Comment 12

what specifically are you going to look for ?

Text Comment. There should be a section in Chapter 1 that summarises all the chapters.

PAGE 10



Comment 13

Is it 10 or 100 nm?



Comment 14

Very short description of each would introduce the reader to the topic

PAGE 11



Comment 15

This picture comes from Wikipedia and should be referenced accordingly



Comment 16

unfiltered what?



Comment 17

Names of chemical elements do not have to be capitalised.



Comment 18

They are alkaline earth metals

PAGE 12



Comment 19

What is KOCH's experiment?

PAGE 13

PAGE 14



Comment 20

What is a grey body?

PAGE 15



Comment 21

If you added descriptions to the spectral lines this spectrum would be easier to read.

PAGE 16



Comment 22

inform about what?

PAGE 17



Comment 23

the small letters are difficult to read

PAGE 18



Comment 24

Use passive voice



Comment 25

being what?

PAGE 19

PAGE 20



Comment 26

You are undermining your efforts with this sentence.

If the software is doing all the work, what is your share? Emphasise it here

PAGE 21



Comment 27

what is this?

PAGE 22

PAGE 23



Comment 28

use the passive voice



Comment 29

why this correction can be used to all compositions if it is based only on D?



Comment 30

what???



Comment 31

seen; the black body graph is missing

PAGE 24



Comment 32

the title is not necessary in the plot area as it is given under the figure

PAGE 25



Comment 33

known

PAGE 26



Comment 34

what?

PAGE 27



Comment 35

where does this information come from? [REF]

PAGE 28



Comment 36

Present all the results in the table; include calculated and corrected temperature, energy density, wavelength, radiance, products of

combustion, etc. It will be much clearer than reading repeatedly the same paragraph



Comment 37

Figure 13 is the Blackbody Curve for Composition D



Comment 38

Title of this graph is missing. What new does this plot bring that is not shown in the previous four ones?



Comment 39

A closing paragraph summarising this chapter should be added at the end.

PAGE 29

PAGE 30

PAGE 31

PAGE 32



Comment 40

What you wrote here fits more the conclusion rather the reflection. Reflection should be more personal. Please, search online what the reflection on completing research project should address.



Comment 41

Errors in authors' names in REFs 9, 10, 11, 14, 15, 23, 26

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