CHAPTER 3

RESULTS AND DISCUSSION
3.1 Studies on IR Flare Compositions Based on High Carbon Content Fuels

A large number of aromatic compounds like anthracene, naphthalene and decacyclene are used as a source of carbon in pyrotechnic IR flare compositions. During this work, data is generated on anthracene based compositions using magnesium and sodium nitrate combination. The rich sources of carbon viz. charcoal as well as graphite are also evaluated.

3.1.1 Magnesium/Sodium nitrate/Graphite Pyrotechnic System

The results obtained for magnesium/sodium nitrate/graphite pyrotechnic systems are discussed in the following text.

i. Sensitivity Data

The results obtained on sensitivity of these compositions are given in table 3.1. All the samples are found insensitive to impact and friction to the maximum limit of test equipment (170 cm and 36 kg respectively). An increase in the ignition temperature of the compositions is observed with increase in graphite content (500 - 552°C).

ii. Combustion Characteristics

A decrease in calor is observed with increase in graphite content and decrease in oxidizer content. Theoretically computed flame temperature also shows similar trend. Thermo-chemical calculations in anaerobic condition reveal that magnesium oxide and carbon monoxide content in the combustion products decreases with increase in graphite content but carbon content increases as expected (table 3.2).

In aerobic condition an increase in combustion temperature is observed. Carbon dioxide content increases on increase in atmospheric oxygen content in the system. Whereas carbon monoxide content decreases beyond 40 parts atmospheric oxygen content of the composition. Carbon content reduces and becomes nil beyond 30 parts atmospheric oxygen of the composition (table 3.3).
iii. **Burn Rate and IR Intensity Data in Different Wave bands**

Burn Rate, IR intensity and IR efficiency results obtained are presented in table 3.4. A few typical IR intensity curves of Mg/NaNO₃/graphite compositions are depicted in fig. 3.1 - 3.8. The values given in tables are average of four readings. It is inferred that burn rate of the compositions decreases with increase in graphite content at the cost of Mg/NaNO₃. IR intensity and IR efficiency also decreases with increase in graphite content in the composition. IR intensity in 3 - 5 μm waveband is more than 2-3μm waveband. The IR spectral ratio $\Phi_{2.3/3.5}$ obtained for the compositions studied is in the range of 0.38 - 0.44. IR intensity in spectral mode could not be recorded for these compositions due to low burn time.

**Table 3.1. Sensitivity Data of Mg/NaNO₃/Graphite Compositions**

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Composition Mg/NaNO₃/Graphite</th>
<th>FOI*</th>
<th>Friction Insensitive (kg)</th>
<th>Ignition Temp. (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>53/27/20</td>
<td>-</td>
<td>36</td>
<td>500</td>
</tr>
<tr>
<td>2</td>
<td>47/23/30</td>
<td>-</td>
<td>36</td>
<td>516</td>
</tr>
<tr>
<td>3</td>
<td>40/20/40</td>
<td>-</td>
<td>36</td>
<td>522</td>
</tr>
<tr>
<td>4</td>
<td>33/17/50</td>
<td>-</td>
<td>36</td>
<td>552</td>
</tr>
</tbody>
</table>

* Insensitive upto 170 cm

**Table 3.2. Combustion Temperature, Combustion Products and Cal val Data of Mg/NaNO₃/Graphite Compositions at Anaerobic Condition**

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Composition Mg/NaNO₃/Graphite</th>
<th>cal val* (cal/g)</th>
<th>Temp. (K)</th>
<th>C (mol/kg)</th>
<th>CO (mol/kg)</th>
<th>MgO (mol/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>53/27/20</td>
<td>1110</td>
<td>1883</td>
<td>16.32</td>
<td>0.332</td>
<td>9.19</td>
</tr>
<tr>
<td>2</td>
<td>47/23/30</td>
<td>1000</td>
<td>1656</td>
<td>24.97</td>
<td>0.001</td>
<td>8.12</td>
</tr>
<tr>
<td>3</td>
<td>40/20/40</td>
<td>811</td>
<td>1602</td>
<td>33.30</td>
<td>0.0002</td>
<td>7.06</td>
</tr>
<tr>
<td>4</td>
<td>33/17/50</td>
<td>708</td>
<td>1594</td>
<td>41.62</td>
<td>0.0001</td>
<td>6.00</td>
</tr>
</tbody>
</table>

* Experimental
Table 3.3. Combustion Temperature and Combustion Products Data of Mg/NaNO₃/Graphite (47/23/30) Compositions at Aerobic Condition

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Oxygen (Parts)</th>
<th>Temp. (K)</th>
<th>CO (mol/kg)</th>
<th>CO₂ (mol/kg)</th>
<th>C (mol/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>2009</td>
<td>5.78</td>
<td>0.000041</td>
<td>16.93</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>2020</td>
<td>11.24</td>
<td>0.000119</td>
<td>9.57</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>2021</td>
<td>15.89</td>
<td>0.000201</td>
<td>3.32</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
<td>2801</td>
<td>17.42</td>
<td>0.422698</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
<td>3096</td>
<td>14.15</td>
<td>0.002496</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 3.4. Burn Rate, IR Intensity and IR Efficiency Data of Mg/NaNO₃/Graphite compositions

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Composition Magnesium/Sodium nitrate/Graphite</th>
<th>LBR (mm/s)</th>
<th>IR Intensity (W/sr)</th>
<th>IR Efficiency (W.s/sr.g)</th>
<th>Φ 2-3/3-5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>2-3 µm</td>
<td>3-5 µm</td>
<td>8-13 µm</td>
</tr>
<tr>
<td>1</td>
<td>53/27/20</td>
<td>18.00</td>
<td>578</td>
<td>1377</td>
<td>221</td>
</tr>
<tr>
<td>2</td>
<td>47/23/30</td>
<td>14.46</td>
<td>425</td>
<td>971</td>
<td>148</td>
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<tr>
<td>3</td>
<td>40/20/40</td>
<td>09.22</td>
<td>246</td>
<td>562</td>
<td>102</td>
</tr>
<tr>
<td>4</td>
<td>33/17/50</td>
<td>07.02</td>
<td>146</td>
<td>384</td>
<td>62</td>
</tr>
</tbody>
</table>
Fig. 3.1: IR Intensity of Mg/NaNO₃/Graphite (53/27/20) in 2-3 µm wave band

Fig. 3.2: IR Intensity of Mg/NaNO₃/Graphite (53/27/20) in 3-5 µm wave band

Fig. 3.3: IR Intensity of Mg/NaNO₃/Graphite (47/23/30) in 2-3 µm wave band
Fig. 3.4: IR Intensity of Mg/NaNO₃/Graphite (47/23/30) in 3-5 µm wave band

Fig. 3.5: IR Intensity of Mg/NaNO₃/Graphite (40/20/40) in 2-3 µm wave band

Fig. 3.6: IR Intensity of Mg/NaNO₃/Graphite ((40/20/40)) in 3-5 µm wave band
Fig. 3.7: IR Intensity of Mg/NaNO₃/Graphite (33/17/50) in 2-3 μm wave band

Fig. 3.8: IR Intensity of Mg/NaNO₃/Graphite (33/17/50) in 3-5 μm wave band
3.1.2 Magnesium/Sodium nitrate/Charcoal Pyrotechnic System

The results obtained for magnesium/sodium nitrate/charcoal pyrotechnic system are discussed in this section. Magnesium/sodium nitrate/graphite (53/27/20) composition is taken as control composition and effect of change in fuel oxidizer content on characteristics of charcoal based compositions is studied whereas the ratio of magnesium/sodium nitrate is kept constant.

i. Sensitivity Data

The test results bring out that the compositions are impact and friction insensitive like graphite based compositions. The ignition temperature of these compositions is almost constant and higher than that of graphite based compositions. It may due to relatively higher thermal conductivity of graphite (table 3.5).

ii. Combustion characteristics

As in case of graphite based compositions cal val decreases with increase in charcoal content and decrease in oxidizer content, whereas theoretical flame temperature remains nearly constant. Both the values are found to be higher than those for graphite based compositions. Thermo-chemical calculations reveal that charcoal content does not have remarkable effect on CO content in the combustion products unlike in case of graphite based compositions. It may be due to presence of internal oxygen in charcoal. Magnesium oxide decreases and carbon content increases in the combustion products with increase in charcoal content as in case of graphite based compositions which may be the cause of the marginal decrease in flame temperature with increase in charcoal content (table. 3.6).

In aerobic condition relatively higher combustion temperature is obtained as more oxidation of carbon occurs to it oxides. All carbon is converted to oxides due to supply of atmospheric oxygen as in case of graphite based composition (table 3.7).

iii. Burn Rate and IR Intensity Data in Different Wave bands

The data on burn rate, IR intensity and IR efficiency of compositions are presented in table 3.8 and fig. 3.9 - 3.16 depict IR intensity curves of charcoal based compositions. The results obtained bring out that burn rate and IR intensity decrease with
increase in charcoal content whereas IR efficiency increases which may be correlate with burn rate pattern. The IR spectral ratio $\Phi_{2-3/3-5}$ is found in the range of 0.34 - 0.42. IR spectral graphs shows that, peak emission at 4.3 $\mu$m reduces on increase in charcoal content (fig 3.17 – 3.20).

**Table 3.5. Sensitivity Data of Mg/NaNO$_3$/Charcoal Compositions**

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Composition Mg/NaNO$_3$/Charcoal</th>
<th>FOI*</th>
<th>Friction Insensitive (kg)</th>
<th>Ignition Temp. ($^\circ$C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>53/27/20</td>
<td>-</td>
<td>36</td>
<td>603</td>
</tr>
<tr>
<td>2</td>
<td>47/23/30</td>
<td>-</td>
<td>36</td>
<td>604</td>
</tr>
<tr>
<td>3</td>
<td>40/20/40</td>
<td>-</td>
<td>36</td>
<td>603</td>
</tr>
<tr>
<td>4</td>
<td>33/17/50</td>
<td>-</td>
<td>36</td>
<td>606</td>
</tr>
</tbody>
</table>

* Insensitive upto 170 cm

**Table 3.6. Combustion Temperature, Combustion Products and Calorimetric Data of Mg/NaNO$_3$/Charcoal compositions at Anaerobic Condition**

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Composition Mg/NaNO$_3$/Charcoal</th>
<th>cal val* (cal/g)</th>
<th>Temp. (K)</th>
<th>C (mol/kg)</th>
<th>CO (mol/kg)</th>
<th>MgO (c) (mol/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>53/27/20</td>
<td>1405</td>
<td>1938</td>
<td>12.52</td>
<td>1.61</td>
<td>9.34</td>
</tr>
<tr>
<td>2</td>
<td>47/23/30</td>
<td>1387</td>
<td>1929</td>
<td>19.74</td>
<td>1.47</td>
<td>8.73</td>
</tr>
<tr>
<td>3</td>
<td>40/20/40</td>
<td>1348</td>
<td>1929</td>
<td>26.57</td>
<td>1.72</td>
<td>8.17</td>
</tr>
<tr>
<td>4</td>
<td>33/17/50</td>
<td>1199</td>
<td>1924</td>
<td>33.39</td>
<td>1.98</td>
<td>7.56</td>
</tr>
</tbody>
</table>

*Experimental
Table 3.7. Combustion Temperature and Combustion Products Data of Mg/NaNO₃/Charcoal (47/23/30) Compositions at Aerobic Condition

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Oxygen (Parts)</th>
<th>Temp. (K)</th>
<th>CO (mol/kg)</th>
<th>CO₂ (mol/kg)</th>
<th>C (mol/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>1992</td>
<td>7.702</td>
<td>0.000059</td>
<td>11.569</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>2003</td>
<td>13.006</td>
<td>0.000138</td>
<td>4.656</td>
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<tr>
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<td>30</td>
<td>2465</td>
<td>16.318</td>
<td>0.031115</td>
<td>0</td>
</tr>
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<td>4</td>
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<td>2990</td>
<td>13.800</td>
<td>1.381225</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
<td>3099</td>
<td>11.561</td>
<td>2.607904</td>
<td>0</td>
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</table>

Table 3.8. Burn Rate, IR Intensity and IR Efficiency Data of Mg/NaNO₃/Charcoal Compositions

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Composition Mg/NaNO₃/Charcoal</th>
<th>LBR (mm/s)</th>
<th>IR Intensity (W/sr)</th>
<th>IR Efficiency (W.s/sr.g)</th>
<th>( \Phi_{2-3/3-5} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>2-3 µm</td>
<td>3-5 µm</td>
<td>8-13 µm</td>
</tr>
<tr>
<td>1</td>
<td>53/27/20</td>
<td>7.0</td>
<td>204</td>
<td>592</td>
<td>73</td>
</tr>
<tr>
<td>2</td>
<td>47/23/30</td>
<td>5.0</td>
<td>161</td>
<td>403</td>
<td>54</td>
</tr>
<tr>
<td>3</td>
<td>40/20/40</td>
<td>4.0</td>
<td>110</td>
<td>283</td>
<td>42</td>
</tr>
<tr>
<td>4</td>
<td>33/17/50</td>
<td>3.0</td>
<td>83</td>
<td>197</td>
<td>36</td>
</tr>
</tbody>
</table>
**Fig. 3.9:** IR Intensity of Mg/NANO$_3$/Charcoal (53/27/20) in 2-3 µm wave band

**Fig. 3.10:** IR Intensity of Mg/NANO$_3$/Charcoal (53/27/20) in 3-5 µm wave band

**Fig. 3.11:** IR Intensity of Mg/NANO$_3$/Charcoal (47/23/30) in 2-3 µm wave band
Fig. 3.12: IR Intensity of Mg/NANO₃/ Charcoal (47/23/30) in 3-5 μm wave band

Fig. 3.13: IR Intensity of Mg/NANO₃/ Charcoal (40/20/40) in 2-3 μm wave band

Fig. 3.14: IR Intensity of Mg/NANO₃/ Charcoal (40/20/40) in 3-5 μm wave band
Fig. 3.15: IR Intensity of Mg/NANO₃/ Charcoal (33/17/50) in 3-5 µm wave band

Fig. 3.16: IR Intensity of Mg/NANO₃/ Charcoal (33/17/50) in 3-5 µm wave band

Fig. 3.17: IR Spectral Graph of Mg/NANO₃/ Charcoal (53/27/20)
Fig. 3.18: IR Spectral Graph of Mg/NANO₃/ Charcoal (47/23/30)

Fig. 3.19: IR Spectral Graph of Mg/NANO₃/ Charcoal (40/20/40)

Fig. 3.20: IR Spectral Graph of Mg/NANO₃/ Charcoal (33/17/50)
3.1.3 Magnesium/Sodium nitrate/Anthracene Pyrotechnic System

The results obtained for magnesium/sodium nitrate/anthracene pyrotechnic system are presented in this section.

i. Sensitivity Data

Anthracene based compositions gave FOI in the range 70 - 90 in impact sensitivity test. However, these compositions are found friction insensitive like graphite and charcoal based compositions. Ignition temperature obtained is in the range of 485 - 510°C (table 3.9).

ii. Combustion Characteristics

Cal val and theoretical flame temperature showed similar trend as for graphite and charcoal based compositions. Thermo-chemical calculations reveal that the CO content is highest for 10% anthracene. MgO content decreases and carbon content increases with increase in anthracene content (table 3.10).

In aerobic condition an increase in combustion temperature is observed accompanied with increases in CO₂ content. Complete conversion of carbon to the oxides takes place at atmospheric oxygen content around 40 parts of the composition (table 3.11).

iii. Burn Rate and IR Intensity Data in Different Wave bands

The burn rate trend obtained for these compositions are similar to those for graphite and charcoal based compositions. IR intensity reduces consistently with increase in anthracene content whereas IR efficiency decreases beyond 30% anthracene content (table 3.12 & fig. 3.21 - 3.28). IR spectral graphs shows that, peak emission at 4.3 µm reduces on increase in anthracene content (fig 3.29 – 3.32)
### Table 3.9. Sensitivity and Calorimetric Data of Mg/NaNO₃ /Anthracene compositions

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Composition Mg/NaNO₃/Anthracene</th>
<th>FOI</th>
<th>Friction Insensitive (kg)</th>
<th>Ignition Temp. (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>57/28/10</td>
<td>73</td>
<td>36</td>
<td>505</td>
</tr>
<tr>
<td>2</td>
<td>53/27/20</td>
<td>91</td>
<td>36</td>
<td>508</td>
</tr>
<tr>
<td>3</td>
<td>47/23/30</td>
<td>70</td>
<td>36</td>
<td>487</td>
</tr>
<tr>
<td>4</td>
<td>40/20/40</td>
<td>89</td>
<td>36</td>
<td>485</td>
</tr>
</tbody>
</table>

### Table 3.10. Temperature and concentration of Combustion Products Data of Mg/NaNO₃ /Anthracene compositions

<table>
<thead>
<tr>
<th>Sr.No.</th>
<th>Composition Mg/NaNO₃/Anthracene</th>
<th>cal val* (cal/g)</th>
<th>Temp. (K)</th>
<th>C (mol/kg)</th>
<th>CO (mol/kg)</th>
<th>MgO (c) (mol/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>57/28/10</td>
<td>1157</td>
<td>1896</td>
<td>7.17</td>
<td>0.653</td>
<td>9.93</td>
</tr>
<tr>
<td>2</td>
<td>53/27/20</td>
<td>1052</td>
<td>1843</td>
<td>15.43</td>
<td>0.243</td>
<td>9.28</td>
</tr>
<tr>
<td>3</td>
<td>47/23/30</td>
<td>860</td>
<td>1856</td>
<td>22.21</td>
<td>0.399</td>
<td>8.76</td>
</tr>
<tr>
<td>4</td>
<td>40/20/40</td>
<td>774</td>
<td>1540</td>
<td>31.40</td>
<td>0.000</td>
<td>7.05</td>
</tr>
</tbody>
</table>

*Experimental
### Table 3.11. Combustion Temperature and Combustion Products Data of Mg/NaNO₃ /Anthracene (47/23/30) Compositions at Aerobic Condition

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Oxygen (Parts)</th>
<th>Temp. (K)</th>
<th>CO (mol/kg)</th>
<th>CO₂ (mol/kg)</th>
<th>C (mol/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>1972</td>
<td>5.56</td>
<td>0.000034</td>
<td>15.80</td>
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<td>20</td>
<td>1992</td>
<td>11.02</td>
<td>0.000103</td>
<td>8.55</td>
</tr>
<tr>
<td>3</td>
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<td>1998</td>
<td>15.67</td>
<td>0.000180</td>
<td>2.40</td>
</tr>
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<td>4</td>
<td>40</td>
<td>2721</td>
<td>16.54</td>
<td>0.286782</td>
<td>0</td>
</tr>
</tbody>
</table>

### Table 3.12. Burn Rate, IR Intensity and IR Efficiency Data of Mg/NaNO₃ /Anthracene compositions

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Composition Mg/NaNO₃ /Anthracene</th>
<th>LBR (mm/s)</th>
<th>IR Intensity (W/sr)</th>
<th>IR Efficiency (W.s/sr.g)</th>
<th>Φ&lt;sub&gt;2-2.4/3-5&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>2-2.4 μm</td>
<td>3-5 μm</td>
<td>8-13 μm</td>
</tr>
<tr>
<td>1</td>
<td>60/30/10</td>
<td>15</td>
<td>191</td>
<td>1782</td>
<td>153</td>
</tr>
<tr>
<td>2</td>
<td>53/27/20</td>
<td>12</td>
<td>219</td>
<td>1697</td>
<td>182</td>
</tr>
<tr>
<td>3</td>
<td>47/23/30</td>
<td>6</td>
<td>195</td>
<td>1468</td>
<td>146</td>
</tr>
<tr>
<td>4</td>
<td>40/20/40</td>
<td>3</td>
<td>68</td>
<td>486</td>
<td>54</td>
</tr>
</tbody>
</table>
Fig. 3.21: IR Intensity of Mg/NaNO$_3$/Anthracene (60/30/10) in 2-2.4 µm wave band

Fig. 3.22: IR Intensity of Mg/NaNO$_3$/Anthracene (60/30/10) in 3-5 µm wave band

Fig. 3.23: IR Intensity of Mg/NaNO$_3$/Anthracene (53/27/20) in 2-2.4 µm wave band
Fig. 3.24: IR Intensity of Mg/NaNO₃/Anthracene (53/27/20) in 3-5 µm wave band

Fig. 3.25a: IR Intensity of Mg/NaNO₃/Anthracene (47/23/30) in 2-2.4 µm wave band

Fig. 3.25b: IR Intensity of Mg/NaNO₃/Anthracene (47/23/30) in 2-3 µm wave band
Fig. 3.26: IR Intensity of Mg/NaNO₃/Anthracene (47/23/30) in 3-5 μm wave band

Fig. 3.27: IR Intensity of Mg/NaNO₃/Anthracene (40/20/40) in 2-2.4 μm wave band

Fig. 3.28: IR Intensity of Mg/NaNO₃/Anthracene (40/20/40) in 3-5 μm wave band
Fig. 3.29: IR Spectral Graph of Mg/NaNO₃/Anthracene (60/30/10)

Fig. 3.30: IR Spectral Graph of Mg/NaNO₃/Anthracene (53/27/20)

Fig. 3.31: IR Spectral Graph of Mg/NaNO₃/Anthracene (47/23/30)
Fig. 3.32: IR Spectral Graph of Mg/NaNO₃/Anthracene (40/20/40)
3.2 Studies on IR Flare Compositions Based on Fluro Polymers

The results obtained on teflon, viton and KeL-F based compositions incorporating sodium nitrate are presented in this sub chapter. The data on standard MTV compositions is generated as a reference. Viton and KeL-F are considered as oxidizer cum binder and carbon source.

3.2.1 MTV System

i. Sensitivity Data

The results are presented in table 3.13. It is observed that increase in fuel oxidizer ratio from 50:50 to 70:30 leads to increase in the F of I value. However, all the compositions are friction insensitive up to 36 kg. Ignition temperature of the composition decreases with increase in magnesium content.

ii. Combustion Characteristics

The cal val of the compositions decreases remarkably from 1750 to 1184 cal/g on increase of magnesium content corresponding to overall fuel - oxidizer ratio from 50:50 - 70:30 in the composition. Flame temperature of composition decreases from 2365 to 1535 K with increase in fuel - oxidizer ratio as predicted by thermo chemical calculations. As expected, the amount of carbon decreases as fuel - oxidizer ratio increases, due to decrease in teflon content, whereas magnesium fluoride (MgF$_2$) content increases (table 3.14).

In aerobic condition an increase in combustion temperature is obtained on increase in the oxygen content. CO$_2$ content increases on increasing atmospheric oxygen content in the system. CO content increases upto 20 parts atmospheric oxygen of the composition and carbon content becomes nil beyond 10 parts atmospheric oxygen of the composition (table 3.15).

iii. Burn Rate and IR Intensity data in Different Wave bands

The results obtained, reveal that burn rate increases from 2.9 - 7.0 mm/s as fuel - oxidizer ratio increases from 50:50 - 70:30. IR intensity increases in all wavebands except 8-13 µm wave band as the fuel -oxidizer ratio increases from 50:50 - 70:30. As
regards IR efficiency, it decreases in all the wavebands as fuel - oxidizer ratio increases from 50:50 - 70:30. The IR spectral ratio $\Phi_{2-3/3-5}$ are in the range of 0.67 - 0.87 (table 3.16 & fig. 3.33 - 3.42). IR spectral graphs shows continuous black body emission (fig 3.43 – 3.47).

**Table 3.13. Sensitivity Data of MTV compositions**

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Composition Magnesium/Teflon/Viton (MTV)</th>
<th>FOI</th>
<th>Friction Insensitive (kg)</th>
<th>Ignition Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>48/48/4</td>
<td>53</td>
<td>36</td>
<td>590</td>
</tr>
<tr>
<td>2</td>
<td>53/43/4</td>
<td>67</td>
<td>36</td>
<td>584</td>
</tr>
<tr>
<td>3</td>
<td>58/38/4</td>
<td>81</td>
<td>36</td>
<td>584</td>
</tr>
<tr>
<td>4</td>
<td>62/34/4</td>
<td>95</td>
<td>36</td>
<td>580</td>
</tr>
<tr>
<td>5</td>
<td>70/26/4</td>
<td>109</td>
<td></td>
<td>573</td>
</tr>
</tbody>
</table>

**Table 3.14. Combustion Temperature, Combustion Products and cal val Data of MTV compositions**

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Composition Magnesium/Teflon/Viton (MTV)</th>
<th>cal val* (cal/g)</th>
<th>Temp. (K)</th>
<th>C (c) (mol/kg)</th>
<th>MgF$_2$ (c) (mol/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>48/48/4</td>
<td>1750</td>
<td>2365</td>
<td>10.66</td>
<td>1.56</td>
</tr>
<tr>
<td>2</td>
<td>53/43/4</td>
<td>1515</td>
<td>2285</td>
<td>9.66</td>
<td>3.69</td>
</tr>
<tr>
<td>3</td>
<td>58/38/4</td>
<td>1425</td>
<td>2166</td>
<td>8.66</td>
<td>5.57</td>
</tr>
<tr>
<td>4</td>
<td>62/34/4</td>
<td>1368</td>
<td>2111</td>
<td>8.33</td>
<td>6.07</td>
</tr>
<tr>
<td>5</td>
<td>70/26/4</td>
<td>1184</td>
<td>1535</td>
<td>6.87</td>
<td>6.48</td>
</tr>
</tbody>
</table>

*Experimental
Table 3.15. Combustion Temperature and Combustion Products Data of MTV (48/48/4) Compositions at Aerobic Condition

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Oxygen (Parts)</th>
<th>Temp. (K)</th>
<th>CO (mol/kg)</th>
<th>CO$_2$ (mol/kg)</th>
<th>C (mol/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>2413</td>
<td>5.68</td>
<td>0.000007</td>
<td>4.01</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>2949</td>
<td>8.19</td>
<td>0.695002</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>3125</td>
<td>6.20</td>
<td>2.000821</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
<td>3155</td>
<td>5.14</td>
<td>2.483695</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
<td>3159</td>
<td>4.39</td>
<td>2.724318</td>
<td>0</td>
</tr>
</tbody>
</table>

Table3.16. Burn Rate, IR Intensity and IR Efficiency Data of MTV compositions

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Composition Mg/Teflon/Viton (MTV)</th>
<th>LBR (mm/s)</th>
<th>IR Intensity (W/sr)</th>
<th>IR Efficiency (W.s/sr.g)</th>
<th>Φ$_{2.3/3-5}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>2-3 µm</td>
<td>3-5 µm</td>
<td>8-13 µm</td>
</tr>
<tr>
<td>1</td>
<td>48/48/4</td>
<td>2.9</td>
<td>484</td>
<td>626</td>
<td>77</td>
</tr>
<tr>
<td>2</td>
<td>53/43/4</td>
<td>4.3</td>
<td>643</td>
<td>800</td>
<td>92</td>
</tr>
<tr>
<td>3</td>
<td>58/38/4</td>
<td>5.4</td>
<td>767</td>
<td>876</td>
<td>109</td>
</tr>
<tr>
<td>4</td>
<td>62/34/4</td>
<td>6.0</td>
<td>744</td>
<td>1063</td>
<td>104</td>
</tr>
<tr>
<td>5</td>
<td>70/26/4</td>
<td>7.0</td>
<td>760</td>
<td>1129</td>
<td>102</td>
</tr>
</tbody>
</table>
Fig. 3.33 IR Intensity of MTV composition (48/48/4) in 2-3 µm wave band

Fig. 3.34 IR Intensity of MTV composition (48/48/4) in 3-5 µm wave band

Fig. 3.35 IR Intensity of MTV composition (53/43/4) in 2-3 µm wave band
Fig. 3.36  IR Intensity of MTV composition (53/43/4) in 3-5 \( \mu \text{m} \) wave band

Fig. 3.37  IR Intensity of MTV composition (58/38/4) in 2-3 \( \mu \text{m} \) wave band

Fig. 3.38  IR Intensity of MTV composition (58/38/4) in 3-5 \( \mu \text{m} \) wave band
Fig. 3.39 IR Intensity of MTV composition (62/34/4) in 2-3 μm wave band

Fig. 3.40 IR Intensity of MTV composition (62/34/4) in 3-5 μm wave band

Fig. 3.41 IR Intensity of MTV composition (70/26/4) in 2-3 μm wave band
Fig. 3.42  IR Intensity of MTV composition (70/26/4) in 3-5 µm wave band

Fig. 3.43  IR Spectral Graph of MTV composition (48/48/4)

Fig. 3.44  IR Spectral Graph of MTV composition (53/43/4)
Fig. 3.45 IR Spectral Graph of MTV composition (58/38/4)

Fig. 3.46 IR Spectral Graph of MTV composition (62/34/4)

Fig. 3.47 IR Spectral Graph of MTV composition (70/26/4)
In view of highest IR intensity and low IR spectral ratio obtained for 70/30 Mg/teflon composition, composition with 30 % magnesium content is taken as reference and sodium nitrate is incorporated as a replacement of fluro polymer. As IR intensity ratio of MTV compositions does not meet the requirements of decoy flare as a counter measure to new generation missile seekers, various compositions are studied during this work by incorporating sodium nitrate as oxidizer.

3.2.2 Magnesium/Sodium nitrate/Teflon Pyrotechnic System

Sodium nitrate is incorporated as a replacement of teflon. The results obtained for magnesium/sodium nitrate/teflon pyrotechnic system are presented in this sub chapter.

i. Sensitivity Data

An increase in FOI is observed on replacement of teflon by sodium nitrate and FOI increases from 109 to 159 on increasing the sodium nitrate content. These compositions are insensitive to impact as compared to MTV based compositions. All compositions are friction insensitive upto 36 kg. Ignition temperature of the compositions ranges from 467 to 519 OC (table 3.17).

ii. Combustion characteristics

Cal val, reduces on increasing the sodium nitrate content. In anaerobic condition flame temperature, CO content and MgO content increases whereas MgF₂ and carbon content reduce in combustion products on increase in sodium nitrate content in the composition (table 3.18). In aerobic condition, flame temperature and CO₂ content increases on increase in atmospheric oxygen in the system. Increase in MgO content is observed upto 20 parts of atmospheric oxygen (table 3.19).

iii. Burn Rate and IR Intensity data in Different Wave bands

Burn rate, IR intensity and IR efficiency results obtained during this study bring out an increase in burn rate of the compositions with increase in sodium nitrate content. It is also brought out that IR intensity increases in 3 - 5 and 8 - 13 µm wavebands and it decreases in wave band of 2 - 2.4 & 2 - 3 µm (table 3.20 and fig 3.43- 3.59). IR efficiency reduces with increase NaNO₃ content. IR intensity in spectral mode could not be recorded for these compositions due to low burn time.
Table 3.17. Impact, Friction Sensitivity and Ignition Temperature of Mg/ Teflon/NaNO₃ compositions

<table>
<thead>
<tr>
<th>Comp. No.</th>
<th>Composition Mg/ Teflon /NaNO₃</th>
<th>F of I</th>
<th>Friction Insensitive (kg)</th>
<th>Ignition temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>70/30/00</td>
<td>109</td>
<td>36</td>
<td>NI</td>
</tr>
<tr>
<td>2</td>
<td>70/25/0</td>
<td>114</td>
<td>36</td>
<td>467</td>
</tr>
<tr>
<td>3</td>
<td>70/20/10</td>
<td>124</td>
<td>36</td>
<td>474</td>
</tr>
<tr>
<td>4</td>
<td>70/15/15</td>
<td>144</td>
<td>36</td>
<td>478</td>
</tr>
<tr>
<td>5</td>
<td>70/10/20</td>
<td>159</td>
<td>36</td>
<td>482</td>
</tr>
<tr>
<td>6</td>
<td>70/05/25</td>
<td>146</td>
<td>36</td>
<td>519</td>
</tr>
</tbody>
</table>

Table 3.18. Thermo-Chemical Data in Anaerobic Condition of Mg/ Teflon/NaNO₃ compositions

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Composition Mg/ Teflon /NaNO₃</th>
<th>Cal.Val (Cal/g)</th>
<th>Temp. (K)</th>
<th>C (c) (mol/kg)</th>
<th>CO (mol/kg)</th>
<th>MgO (mol/kg)</th>
<th>MgF₂(c) (mol/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>70/30/00</td>
<td>1484</td>
<td>1366</td>
<td>5.99</td>
<td>-</td>
<td>-</td>
<td>5.99</td>
</tr>
<tr>
<td>2</td>
<td>70/25/0</td>
<td>1405</td>
<td>1521</td>
<td>4.99</td>
<td>0.000026</td>
<td>1.76</td>
<td>4.98</td>
</tr>
<tr>
<td>3</td>
<td>70/20/10</td>
<td>1278</td>
<td>1560</td>
<td>3.52</td>
<td>0.000090</td>
<td>3.52</td>
<td>3.98</td>
</tr>
<tr>
<td>4</td>
<td>70/15/15</td>
<td>1153</td>
<td>1591</td>
<td>2.99</td>
<td>0.000245</td>
<td>5.29</td>
<td>2.97</td>
</tr>
<tr>
<td>5</td>
<td>70/10/20</td>
<td>1132</td>
<td>1601</td>
<td>1.99</td>
<td>0.000359</td>
<td>7.05</td>
<td>1.96</td>
</tr>
<tr>
<td>6</td>
<td>70/05/25</td>
<td>1098</td>
<td>1688</td>
<td>0.99</td>
<td>0.004235</td>
<td>8.81</td>
<td>0.92</td>
</tr>
</tbody>
</table>
Table 3.19 Thermo-Chemical Data in Aerobic Condition of Mg/ Teflon/NaNO₃ compositions

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Composition Mg/NaNO₃/Teflon (70/20/10)</th>
<th>Temp. (K)</th>
<th>CO (mol/kg)</th>
<th>CO₂ (mol/kg)</th>
<th>MgO (c) (mol/kg)</th>
<th>MgF₂(c) (mol/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10 Parts O₂</td>
<td>3034</td>
<td>1.73</td>
<td>0.08</td>
<td>9.42</td>
<td>0.63</td>
</tr>
<tr>
<td>2</td>
<td>20 Parts O₂</td>
<td>3244</td>
<td>1.41</td>
<td>0.24</td>
<td>10.45</td>
<td>0.58</td>
</tr>
<tr>
<td>3</td>
<td>30 Parts O₂</td>
<td>3298</td>
<td>1.18</td>
<td>0.35</td>
<td>10.34</td>
<td>0.56</td>
</tr>
<tr>
<td>4</td>
<td>40 Parts O₂</td>
<td>3307</td>
<td>1.00</td>
<td>0.40</td>
<td>10.21</td>
<td>0.55</td>
</tr>
<tr>
<td>5</td>
<td>50 Parts O₂</td>
<td>3301</td>
<td>0.89</td>
<td>0.44</td>
<td>10.00</td>
<td>0.53</td>
</tr>
</tbody>
</table>

Table 3.20. IR Intensity and Burning Rates of Mg/ Teflon/NaNO₃ compositions

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Composition Mg/ Teflon/NaNO₃</th>
<th>LBR (mm/s)</th>
<th>IR Intensity (W/sr)</th>
<th>IR Efficiency (W.s/sr.g)</th>
<th>Φ 2-3/3-5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>2-2.4 µm</td>
<td>2-3 µm</td>
<td>3-5 µm</td>
</tr>
<tr>
<td>1</td>
<td>70/25/0</td>
<td>5.4</td>
<td>102</td>
<td>431</td>
<td>686</td>
</tr>
<tr>
<td>2</td>
<td>70/20/10</td>
<td>7.0</td>
<td>124</td>
<td>466</td>
<td>789</td>
</tr>
<tr>
<td>3</td>
<td>70/15/15</td>
<td>11.0</td>
<td>121</td>
<td>417</td>
<td>988</td>
</tr>
<tr>
<td>4</td>
<td>70/10/20</td>
<td>15.0</td>
<td>96</td>
<td>374</td>
<td>1081</td>
</tr>
<tr>
<td>5</td>
<td>70/05/25</td>
<td>19.0</td>
<td>90</td>
<td>332</td>
<td>1102</td>
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<tr>
<td>6</td>
<td></td>
<td>28.0</td>
<td>61</td>
<td>215</td>
<td>839</td>
</tr>
</tbody>
</table>
Fig. 3.48 IR intensity of Mg/Teflon/NaNO₃ (70/30/00) in 2-3 µm wave band

Fig. 3.49 IR intensity of Mg/Teflon/NaNO₃ (70/30/00) in 3-5 µm wave band

Fig. 3.50 IR intensity of Mg/Teflon/NaNO₃ (70/25/5) in 2-3 µm wave band
Fig. 3.51 IR intensity of Mg/Teflon/NaNO₃ (70/25/5) in 3-5 µm wave band

Fig. 3.52 IR intensity of Mg/Teflon/NaNO₃ (70/20/10) in 2-3 µm wave band

Fig. 3.53 IR intensity of Mg/Teflon/NaNO₃ (70/20/10) in 3-5 µm wave band
Fig. 3.54 IR intensity of Mg/Teflon/NaNO₃ (70/15/15) in 2-3 µm wave band

Fig. 3.55 IR intensity of Mg/Teflon/NaNO₃ (70/15/15) in 3-5 µm wave band

Fig. 3.56 IR intensity of Mg/Teflon/NaNO₃ (70/10/20) in 2-3 µm wave band
Fig. 3.57 IR intensity of Mg/Teflon/NaNO₃ (70/10/20) in 3-5 µm wave band

Fig. 3.58 IR intensity of Mg/Teflon/NaNO₃ (70/05/25) in 2-3 µm wave band

Fig. 3.59 IR intensity of Mg/Teflon/NaNO₃ (70/05/25) in 3-5 µm wave band
3.2.3 Magnesium/Sodium nitrate/viton and Magnesium/Sodium Nitrate/KeL-F Pyrotechnic System

The results obtained for magnesium/sodium nitrate/viton and magnesium/sodium nitrate/KeL-F pyrotechnic systems are presented in this sub chapter.

i. Sensitivity Data

Sensitivity results obtained for viton and KeL-F based compositions are presented in table 3.21. It is seen that all these compositions are insensitive to friction upto 36 kg. However, FOI of viton based compositions is found to be remarkably low compare to corresponding teflon/NaNO₃ compositions and marginally higher compared to MTV. KeL-F based compositions are found to be comparable to teflon based compositions in terms of FOI. This may be attributed to the different physical nature of selected fluoro polymer resulting in more intimate mixture of the ingredients particularly in case of viton.

ii. Combustion characteristics

Thermo-chemical calculations data bring out that flame temperature pattern and combustion products profile follows trend similar to teflon based compositions in aerobic and anaerobic condition (table 3.22 and 3.23).

iii. Burn Rate and IR Intensity data in Different Wave bands

Burn rate, IR intensity and IR efficiency results of these compositions also follows similar trend as corresponding teflon based compositions. The IR spectral ratio ($\Phi_{2.3/3.5}$) of these compositions reduces from 0.61 to 0.42 for viton and 0.63 to 0.36 for KeL-F based compositions probably due to increase in content of oxides of carbon and decrease in carbon content in combustion products (table 3.24 & fig 3.60 -3.71).

IR intensity curves of compositions in spectral mode show strong peak emission at 4.0 - 5.0 µm corresponding to CO/CO₂ emission and peak emission at 4.3µm increases on increasing NaNO₃ and reducing the flurodropomers (fig 3.72 - 3.77).
Table 3.21: Impact and Friction Sensitivity of Mg/NaNO₃/ Viton and Mg/NaNO₃/ KeL-F Compositions

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Composition Mg/NaNO₃/Viton</th>
<th>F of I</th>
<th>Friction insensitive (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>70/00/30</td>
<td>46</td>
<td>36</td>
</tr>
<tr>
<td>2</td>
<td>70/10/20</td>
<td>50</td>
<td>36</td>
</tr>
<tr>
<td>3</td>
<td>70/20/10</td>
<td>60</td>
<td>36</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Composition Mg/NaNO₃/KeL-F</th>
<th>F of I</th>
<th>Friction insensitive (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>70/00/30</td>
<td>108</td>
<td>36</td>
</tr>
<tr>
<td>2</td>
<td>70/10/20</td>
<td>104</td>
<td>36</td>
</tr>
<tr>
<td>3</td>
<td>70/20/10</td>
<td>102</td>
<td>36</td>
</tr>
</tbody>
</table>

Table 3.22: Thermo-Chemical Data in Anaerobic Condition of Mg/NaNO₃/ Viton and Mg/NaNO₃/ KeL-F Compositions

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Composition Mg/NaNO₃/Viton</th>
<th>Temp. (K)</th>
<th>cal val (cal/g)</th>
<th>C (c) (mol/kg)</th>
<th>CO (mol/kg)</th>
<th>MgO (c) (mol/kg)</th>
<th>MgF₂ (c) (mol/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>70/00/30</td>
<td>1343</td>
<td>1350</td>
<td>7.0</td>
<td>-</td>
<td>-</td>
<td>5.60</td>
</tr>
<tr>
<td>2</td>
<td>70/10/20</td>
<td>1349</td>
<td>1228</td>
<td>4.67</td>
<td>-</td>
<td>3.52</td>
<td>3.73</td>
</tr>
<tr>
<td>3</td>
<td>70/20/10</td>
<td>1577</td>
<td>1086</td>
<td>2.33</td>
<td>-</td>
<td>7.05</td>
<td>1.84</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Composition Mg/NaNO₃/KeL-F</th>
<th>Temp. (K)</th>
<th>cal val (cal/g)</th>
<th>C (c) (mol/kg)</th>
<th>CO (mol/kg)</th>
<th>MgO (c) (mol/kg)</th>
<th>MgF₂ (c) (mol/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>70/00/30</td>
<td>1051</td>
<td>1386</td>
<td>6.56</td>
<td>-</td>
<td>-</td>
<td>4.15</td>
</tr>
<tr>
<td>5</td>
<td>70/10/20</td>
<td>1345</td>
<td>1184</td>
<td>4.43</td>
<td>-</td>
<td>3.52</td>
<td>2.76</td>
</tr>
<tr>
<td>6</td>
<td>70/20/10</td>
<td>1521</td>
<td>1049</td>
<td>2.21</td>
<td>-</td>
<td>7.05</td>
<td>1.37</td>
</tr>
</tbody>
</table>
Table 3.23. Thermo-Chemical Data in Aerobic Condition of Mg/NaNO₃/Viton A and Mg/NaNO₃/KeL-F compositions

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Comp. Mg/NaNO₃/Viton A</th>
<th>Temp. (K)</th>
<th>C (c) (mol/kg)</th>
<th>CO (mol/kg)</th>
<th>CO₂ (mol/kg)</th>
<th>MgO (mol/kg)</th>
<th>MgF₂(c) (mol/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 parts Oxygen</td>
<td>1577</td>
<td>2.33</td>
<td>-</td>
<td>-</td>
<td>7.05</td>
<td>1.84</td>
</tr>
<tr>
<td>2</td>
<td>10 parts Oxygen</td>
<td>2754</td>
<td>-</td>
<td>2.10</td>
<td>0.01</td>
<td>9.84</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>20 parts Oxygen</td>
<td>3198</td>
<td>-</td>
<td>1.70</td>
<td>0.23</td>
<td>11.18</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>30 parts Oxygen</td>
<td>3281</td>
<td>-</td>
<td>1.41</td>
<td>0.38</td>
<td>11.01</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>40 parts Oxygen</td>
<td>3296</td>
<td>-</td>
<td>1.20</td>
<td>0.46</td>
<td>10.83</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>50 parts Oxygen</td>
<td>3292</td>
<td>-</td>
<td>1.04</td>
<td>0.50</td>
<td>10.65</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Mg/NaNO₃/KeL-F (70/20/10)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0 parts O₂</td>
<td>1521</td>
<td>2.21</td>
<td>-</td>
<td>-</td>
<td>7.05</td>
<td>1.37</td>
</tr>
<tr>
<td>8</td>
<td>10 parts O₂</td>
<td>2639</td>
<td>-</td>
<td>2.00</td>
<td>0.006</td>
<td>10.03</td>
<td>-</td>
</tr>
<tr>
<td>9</td>
<td>20 parts O₂</td>
<td>3187</td>
<td>-</td>
<td>1.63</td>
<td>0.21</td>
<td>11.60</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>30 parts O₂</td>
<td>3280</td>
<td>-</td>
<td>1.34</td>
<td>0.35</td>
<td>11.42</td>
<td>-</td>
</tr>
<tr>
<td>11</td>
<td>40 parts O₂</td>
<td>3297</td>
<td>-</td>
<td>1.14</td>
<td>0.43</td>
<td>11.23</td>
<td>-</td>
</tr>
<tr>
<td>12</td>
<td>50 parts O₂</td>
<td>3293</td>
<td>-</td>
<td>0.99</td>
<td>0.47</td>
<td>11.03</td>
<td>-</td>
</tr>
<tr>
<td>Sr. No.</td>
<td>Composition</td>
<td>LBR (mm/s)</td>
<td>IR Intensity (W/sr)</td>
<td>IR Efficiency (W.s/sr.g)</td>
<td>Φ 2-3/3-5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>--------------------</td>
<td>------------</td>
<td>---------------------</td>
<td>--------------------------</td>
<td>-----------</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mg/NaNO₃/Viton</td>
<td></td>
<td>2-2.4 μm</td>
<td>2-3 μm</td>
<td>3-5 μm</td>
<td>8-13 μm</td>
<td>2-2.4μm</td>
</tr>
<tr>
<td>1</td>
<td>70/00/30</td>
<td>8.5</td>
<td>225</td>
<td>1025</td>
<td>1678</td>
<td>168</td>
<td>57</td>
</tr>
<tr>
<td>2</td>
<td>70/10/20</td>
<td>9.5</td>
<td>190</td>
<td>575</td>
<td>940</td>
<td>130</td>
<td>32</td>
</tr>
<tr>
<td>3</td>
<td>70/20/10</td>
<td>11.0</td>
<td>54</td>
<td>256</td>
<td>600</td>
<td>110</td>
<td>10</td>
</tr>
<tr>
<td>1</td>
<td>Mg/NaNO₃/KeL-F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>70/00/30</td>
<td>6.0</td>
<td>177</td>
<td>542</td>
<td>861</td>
<td>99</td>
<td>61</td>
</tr>
<tr>
<td>2</td>
<td>70/10/20</td>
<td>8.0</td>
<td>100</td>
<td>338</td>
<td>711</td>
<td>133</td>
<td>28</td>
</tr>
<tr>
<td>3</td>
<td>70/20/10</td>
<td>11.0</td>
<td>56</td>
<td>197</td>
<td>545</td>
<td>155</td>
<td>12</td>
</tr>
</tbody>
</table>
Fig. 3.60 IR intensity of Mg/Viton/NaNO₃ (70/30/00) in 2-3 μm wave band

Fig. 3.61 IR intensity of Mg/Viton/NaNO₃ (70/30/00) in 3-5 μm wave band

Fig. 3.62 IR intensity of Mg/Viton/NaNO₃ (70/20/10) in 2-3 μm wave band
Fig. 3.63 IR intensity of Mg/Viton/NaNO₃ (70/20/10) in 3-5 μm wave band

Fig. 3.64 IR intensity of Mg/Viton/NaNO₃ (70/10/20) in 2-3 μm wave band

Fig. 3.65 IR intensity of Mg/Viton/NaNO₃ (70/10/20) in 3-5 μm wave band
Fig. 3.66 IR intensity of Mg/KeL-F/NaNO₃ (70/30/00) in 2-3 µm wave band

Fig. 3.67 IR intensity of Mg/Viton/NaNO₃ (70/30/00) in 3-5 µm wave band

Fig. 3.68 IR intensity of Mg/KeL-F/NaNO₃ (70/20/10) in 2-3 µm wave band
Fig. 3.69 IR intensity of Mg/KeL-F/NaNO$_3$ (70/20/10) in 3-5 µm wave band

Fig. 3.70 IR intensity of Mg/KeL-F/NaNO$_3$ (70/10/20) in 2-3 µm wave band

Fig. 3.71 IR intensity of Mg/KeL-F/NaNO$_3$ (70/10/20) in 3-5 µm wave band
Fig. 3.72 IR Spectral Graph of Mg/NaNO₃/viton (70/00/30)

Fig. 3.73 IR Spectral Graph of Mg/NaNO₃/viton (70/10/20)

Fig. 3.74 IR Spectral Graph of Mg/NaNO₃/viton (70/20/10)
Fig. 3.75 IR Spectral Graph of Mg/NaNO₃/KeL-F (70/00/30)

Fig. 3.76 IR Spectral Graph of Mg/NaNO₃/KeL-F (70/10/20)

Fig. 3.77 IR Spectral Graph of Mg/NaNO₃/KeL-F (70/20/10)
3.3 IR Flare Compositions Based on Partially Oxidized Carbonaceous Fuels

3.3. Pyrotechnic Compositions Based on POCF

The IR intensity ratio achieved by the Mg/Teflon/NaNO₃ pyrotechnic system meets the requirement of spectrally matched IR decoy flares. In an attempt to further bring down the IR intensity ratio and burn rate, compositions based on partially oxidized carbonaceous fuels like PA, SA, BTDA and BPTA are studied. Anhydride is kept constant (18%), NaNO₃ content varied from 70 - 20 % and magnesium content from 10 - 60 % with viton binder (2%).

3.3.1 Phthalic Anhydride Based Composition

The results obtained for Mg/NaNO₃/PA/viton pyrotechnic system is discussed under this section.

i. Sensitivity Data

The figure of insensitivity of the compositions ranges from 82 - 128 bringing out that these are relatively safer than MTV. All the compositions are found friction insensitive up to 36 kg (table 3.25).

ii. Combustion Characteristics

Calorimetric data of the compositions are given in table 3.26. It increases with magnesium content (up to 30 %) unlike other compositions studied during this work. This may be due to difference in stoichiometric ratio of these compositions.

Combustion temperature increases up to 30 % magnesium content. In combustion products CO and MgO content increases with increases in magnesium content whereas CO₂ and H₂O reduces on increasing upto 30 % magnesium. On further increase in magnesium content carbon is predicted in the combustion products whereas CO₂ and H₂O are absent (table 3.26)

An increase in combustion temperature is obtained on increase in atmospheric oxygen content upto 20 parts of the composition. With increase in atmospheric oxygen proportion increase in CO₂ content and decrease in CO and H₂O content is observed (table 3.27).
iii. **Burn Rate and IR Intensity data in Different Wave bands**

Burn rate results of the compositions are presented in table 3.28. An increase in burn rate is observed with increase in magnesium content upto 50%. High burn rate at 50% magnesium based composition can be attributed to high thermal conductivity of the composition due to high metal content.

An increase in IR Intensity and IR efficiency is also observed on increase in magnesium content. IR spectral ratio ($\Phi_{2.3/3.5}$) reduces up to 30% magnesium and then it increases. Although, IR Spectral ratio is found to be less than that for MTV, it is relatively more than for Mg/teflon/NaNO$_3$ based composition (table 3.28 & fig 3.78 - 3.89)

IR intensity curves of compositions in spectral mode also show a strong peak emission at 4.0 - 5.0 $\mu$m similar to fluro ploymer based compositions (table 3.29 & fig 3.90 - 3.95).
Table 3.25. Sensitivity and Calorimetric Data of Phthalic Anhydride (PA) based compositions

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Composition Mg/NaNO₃/PA/Viton</th>
<th>FOI</th>
<th>Friction Insensitive (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10/70/18/2</td>
<td>93</td>
<td>36</td>
</tr>
<tr>
<td>2</td>
<td>20/60/18/2</td>
<td>99</td>
<td>36</td>
</tr>
<tr>
<td>3</td>
<td>30/50/18/2</td>
<td>99</td>
<td>36</td>
</tr>
<tr>
<td>4</td>
<td>40/40/18/2</td>
<td>82</td>
<td>36</td>
</tr>
<tr>
<td>5</td>
<td>50/30/18/2</td>
<td>97</td>
<td>36</td>
</tr>
<tr>
<td>6</td>
<td>60/20/18/2</td>
<td>128</td>
<td>36</td>
</tr>
</tbody>
</table>

Table 3.26. Temperature, Combustion Products and cal val Data of Phthalic Anhydride (PA) based compositions in anaerobic condition

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Composition Mg/NaNO₃/PA/Viton</th>
<th>cal val (cal/g)</th>
<th>Temp. (K)</th>
<th>CO (mol/kg)</th>
<th>CO₂ (mol/kg)</th>
<th>C (c) (mol/kg)</th>
<th>H₂O (mol/kg)</th>
<th>MgO (c) (mol/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10/70/18/2</td>
<td>835</td>
<td>2083</td>
<td>0.31</td>
<td>9.88</td>
<td>-</td>
<td>1.23</td>
<td>0.411</td>
</tr>
<tr>
<td>2</td>
<td>20/60/18/2</td>
<td>1225</td>
<td>2660</td>
<td>6.14</td>
<td>4.04</td>
<td>-</td>
<td>1.70</td>
<td>0.0807</td>
</tr>
<tr>
<td>3</td>
<td>30/50/18/2</td>
<td>1560</td>
<td>2712</td>
<td>9.76</td>
<td>0.42</td>
<td>-</td>
<td>0.48</td>
<td>0.1000</td>
</tr>
<tr>
<td>4</td>
<td>40/40/18/2</td>
<td>1500</td>
<td>1983</td>
<td>8.81</td>
<td>0.00</td>
<td>1.32</td>
<td>0.00</td>
<td>0.0894</td>
</tr>
<tr>
<td>5</td>
<td>50/30/18/2</td>
<td>1325</td>
<td>1981</td>
<td>4.77</td>
<td>0.00</td>
<td>5.3</td>
<td>0.00</td>
<td>0.0945</td>
</tr>
<tr>
<td>6</td>
<td>60/20/18/2</td>
<td>1150</td>
<td>1917</td>
<td>0.87</td>
<td>0.00</td>
<td>9.3</td>
<td>0.00</td>
<td>0.0983</td>
</tr>
</tbody>
</table>
Table 3.27: Combustion Temperature and Combustion products of Mg/NaNO₃/PA/Viton (30/50/18/2) Composition in Aerobic condition

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Oxygen (Parts)</th>
<th>T (K)</th>
<th>CO (mol/kg)</th>
<th>CO₂ (mol/kg)</th>
<th>H₂O (mol/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>3010</td>
<td>6.53</td>
<td>2.74</td>
<td>1.15</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>3040</td>
<td>4.89</td>
<td>3.60</td>
<td>1.08</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>3035</td>
<td>3.89</td>
<td>3.95</td>
<td>1.00</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
<td>3018</td>
<td>3.18</td>
<td>4.10</td>
<td>0.94</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
<td>2996</td>
<td>2.64</td>
<td>4.16</td>
<td>0.89</td>
</tr>
</tbody>
</table>

Table 3.28. Burn Rate, IR Intensity and IR Efficiency Data of Phthalic Anhydride (PA) based compositions

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Composition Mg/NaNO₃/PA/Viton</th>
<th>LBR (mm/s)</th>
<th>IR Intensity (W/sr)</th>
<th>IR Efficiency (W.s/sr.g)</th>
<th>Φ 2-3/3-5</th>
<th>Φ 1.1-2.5/3-5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.1-2.5 µm</td>
<td>2-3 µm</td>
<td>3-5 µm</td>
<td>8-13 µm</td>
</tr>
<tr>
<td>1</td>
<td>10/70/18/2</td>
<td>1.1</td>
<td>24</td>
<td>17</td>
<td>28</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>20/60/18/2</td>
<td>2.0</td>
<td>27</td>
<td>20</td>
<td>55</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>30/50/18/2</td>
<td>2.9</td>
<td>57</td>
<td>35</td>
<td>113</td>
<td>14</td>
</tr>
<tr>
<td>4</td>
<td>40/40/18/2</td>
<td>3.3</td>
<td>102</td>
<td>62</td>
<td>151</td>
<td>19</td>
</tr>
<tr>
<td>5</td>
<td>50/30/18/2</td>
<td>8.6</td>
<td>141</td>
<td>89</td>
<td>254</td>
<td>58</td>
</tr>
<tr>
<td>6</td>
<td>60/20/18/2</td>
<td>8.3</td>
<td>249</td>
<td>159</td>
<td>354</td>
<td>69</td>
</tr>
</tbody>
</table>
**Table 3.29 : Peak position and peak intensity values of Phthalic anhydride based compositions**

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Composition Mg/NaNO₃/PA/Viton</th>
<th>Peak Position µm</th>
<th>Peak Intensity W/sr</th>
<th>Peak Position µm</th>
<th>Peak Intensity W/sr</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10/70/18/2</td>
<td>2.7</td>
<td>75</td>
<td>4.3</td>
<td>293</td>
</tr>
<tr>
<td>2</td>
<td>20/60/18/2</td>
<td>2.7</td>
<td>-</td>
<td>4.3</td>
<td>310</td>
</tr>
<tr>
<td>3</td>
<td>30/50/18/2</td>
<td>2.7</td>
<td>140</td>
<td>4.3</td>
<td>204</td>
</tr>
<tr>
<td>4</td>
<td>40/40/18/2</td>
<td>2.7</td>
<td>141</td>
<td>4.3</td>
<td>570</td>
</tr>
<tr>
<td>5</td>
<td>50/30/18/2</td>
<td>2.7</td>
<td>172</td>
<td>4.3</td>
<td>554</td>
</tr>
<tr>
<td>6</td>
<td>60/20/18/2</td>
<td>2.7</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Fig. 3.78 IR intensity of Mg/ NaNO₃/PA/Viton (10/70/18/2) in 2-3 µm wave band

Fig. 3.79 IR intensity of Mg/ NaNO₃/PA/Viton (10/70/18/2) in 3-5 µm wave band

Fig. 3.80 IR intensity of Mg/ NaNO₃/PA/Viton (20/60/18/2) in 2-3 µm wave band
Fig. 3.81 IR intensity of Mg/NaNO₃/PA/Viton (20/60/18/2) in 3-5 µm wave band

Fig. 3.82 IR intensity of Mg/NaNO₃/PA/Viton (30/50/18/2) in 2-3 µm wave band

Fig. 3.83 IR intensity of Mg/NaNO₃/PA/Viton (30/50/18/2) in 3-5 µm wave band
Fig. 3.84 IR intensity of Mg/ NaNO₃/PA/Viton (40/40/18/2) in 2-3 µm wave band

Fig. 3.85  IR intensity of Mg/ NaNO₃/PA/Viton (40/40/18/2) in 3-5 µm wave band

Fig. 3.86 IR intensity of Mg/ NaNO₃/PA/Viton (50/30/18/2) in 2-3 µm wave band
Fig. 3.87 IR intensity of Mg/NaNO₃/PA/Viton (50/30/18/2) in 3-5 µm wave band

Fig. 3.88 IR intensity of Mg/NaNO₃/PA/Viton (60/20/18/2) in 2-3 µm wave band

Fig. 3.89 IR intensity of Mg/NaNO₃/PA/Viton (60/20/18/2) in 3-5 µm wave band
Fig. 3.90  IR Spectral Graph of Mg/ NaNO₃/PA/Viton (10/70/18/2)

Fig. 3.91  IR Spectral Graph of Mg/ NaNO₃/PA/Viton (20/60/18/2)

Fig. 3.92  IR Spectral Graph of Mg/ NaNO₃/PA/Viton (30/50/18/2)
Fig. 3.93  IR Spectral Graph of Mg/ NaNO$_3$/PA/Viton (40/40/18/2)

Fig. 3.94  IR Spectral Graph of Mg/ NaNO$_3$/PA/Viton (50/30/18/2)

Fig. 3.95  IR Spectral Graph of Mg/ NaNO$_3$/PA/Viton (60/20/18/2)
As IR spectral ratio $\Phi_{2-3/3-5}$ of the magnesium/sodium nitrate/phthalic anhydride/viton compositions studied (3.3.1) is less than that of the conventional MTV compositions, SA, BTDA and BPTA are also evaluated as partially oxidized fuels.

3.3.2 Succinic Anhydride Based Compositions

The parameters studied for Mg/NaNO$_3$/PA/viton pyrotechnic system is presented in this section.

i. Sensitivity Data

The results bring out that SA based compositions are found relatively more sensitive than PA based compositions. All the compositions are friction insensitive up to 36 kg (table 3.30).

ii. Combustion characteristics

As in case of PA based compositions calorimetric value increases up to 30 % magnesium and combustion temperature also increases up to 30 % magnesium content. However, CO and MgO content increases up to 40 % magnesium along with decrease in CO$_2$ and H$_2$O this may be outcome of reduction in internal oxygen. CO$_2$ and H$_2$O are absent beyond 40 % magnesium content. Carbon content is nil up to 40 % magnesium beyond that it increases (table 3.31).

Unlike PA based composition combustion temperature reduces on increasing the oxygen due to better oxygen balance of SA. With increase in atmospheric oxygen proportion an increase in CO$_2$ content and decrease in CO and H$_2$O content is observed, the trends observed are similar to PA based compositions (table 3.32).

iii. Burn Rate and IR Intensity Data in Different Wave bands

Burn rate increases with increase in magnesium up to 50 % as in case of PA based compositions. IR Intensity and IR efficiency trends observed are also similar to PA based compositions. However, IR spectral ratio $\Phi_{2-3/3-5}$ reduces up to 40 % magnesium. IR Intensity ratio of these compositions is less than the other compositions studied during this work (table 3.33 & fig. 3.96-3.107).
IR intensity curves of SA based compositions in spectral mode show a strong peak emission at 4.0 - 5.0 µm similar to PA based compositions. However, there is difference in peak intensity values (table 3.34 & fig 3.108 - 3.113).

**Table 3.30. Sensitivity Data of Succinic Anhydride (SA) Based Compositions**

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Composition Mg/NaNO₃/SA/Viton</th>
<th>FOI</th>
<th>Friction Insensitive (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10/70/18/2</td>
<td>61</td>
<td>36</td>
</tr>
<tr>
<td>2</td>
<td>20/60/18/2</td>
<td>58</td>
<td>36</td>
</tr>
<tr>
<td>3</td>
<td>30/50/18/2</td>
<td>69</td>
<td>36</td>
</tr>
<tr>
<td>4</td>
<td>40/40/18/2</td>
<td>69</td>
<td>36</td>
</tr>
<tr>
<td>5</td>
<td>50/30/18/2</td>
<td>73</td>
<td>36</td>
</tr>
<tr>
<td>6</td>
<td>60/20/18/2</td>
<td>90</td>
<td>36</td>
</tr>
</tbody>
</table>

**Table 3.31. Temperature, Combustion Products and cal val Data of Succinic Anhydride (SA) Based Compositions in Anaerobic Condition**

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Composition Mg/NaNO₃/SA/Viton</th>
<th>cal.val (cal/g)</th>
<th>Temp. (K)</th>
<th>CO (mol/kg)</th>
<th>CO₂ (mol/kg)</th>
<th>H₂O (mol/kg)</th>
<th>C (c) (mol/kg)</th>
<th>MgO (c) (mol/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10/70/18/2</td>
<td>1352</td>
<td>1944</td>
<td>0.01</td>
<td>6.74</td>
<td>1.65</td>
<td>-</td>
<td>4.1</td>
</tr>
<tr>
<td>2</td>
<td>20/60/18/2</td>
<td>1240</td>
<td>2626</td>
<td>2.32</td>
<td>5.34</td>
<td>2.80</td>
<td>-</td>
<td>8.16</td>
</tr>
<tr>
<td>3</td>
<td>30/50/18/2</td>
<td>1525</td>
<td>2902</td>
<td>6.10</td>
<td>1.56</td>
<td>1.89</td>
<td>-</td>
<td>10.67</td>
</tr>
<tr>
<td>4</td>
<td>40/40/18/2</td>
<td>1460</td>
<td>2699</td>
<td>7.53</td>
<td>0.12</td>
<td>0.33</td>
<td>-</td>
<td>11.24</td>
</tr>
<tr>
<td>5</td>
<td>50/30/18/2</td>
<td>1372</td>
<td>1982</td>
<td>5.94</td>
<td>0.00</td>
<td>0.00</td>
<td>1.67</td>
<td>10.04</td>
</tr>
<tr>
<td>6</td>
<td>60/20/18/2</td>
<td>1350</td>
<td>1949</td>
<td>1.97</td>
<td>0.00</td>
<td>0.00</td>
<td>5.65</td>
<td>10.48</td>
</tr>
</tbody>
</table>
### Table 3.32: Temperature and Combustion Products Data of Mg/NaNO₃/SA/Viton (30/50/18/2) Based Compositions in Aerobic Condition

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Oxygen (Parts)</th>
<th>Temp. (K)</th>
<th>CO (mol/kg)</th>
<th>CO₂ (mol/kg)</th>
<th>H₂O (mol/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>2997</td>
<td>4.07</td>
<td>2.90</td>
<td>1.99</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>2995</td>
<td>3.04</td>
<td>3.35</td>
<td>1.86</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>2974</td>
<td>2.37</td>
<td>3.53</td>
<td>1.74</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
<td>2945</td>
<td>1.88</td>
<td>3.59</td>
<td>1.64</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
<td>2913</td>
<td>1.51</td>
<td>3.60</td>
<td>1.55</td>
</tr>
</tbody>
</table>

### Table 3.33. Burn Rate, IR Intensity and IR Efficiency Data of Succinic Anhydride (SA) Based compositions

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Composition</th>
<th>LBR (mm/s)</th>
<th>IR Intensity (W/sr)</th>
<th>IR Efficiency (W.s/sr.g)</th>
<th>IR Ratio 1.1-2.5/3-5</th>
<th>IR Ratio 2-3/3-5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mg/NaNO₃/SA/Viton 10/70/18/2</td>
<td>1.00</td>
<td>17 9 36 5 33 22 73 11</td>
<td>0.24 0.47</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Mg/NaNO₃/SA/Viton 20/60/18/2</td>
<td>2.50</td>
<td>25 17 93 10 20 14 76 8 0.18 0.26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Mg/NaNO₃/SA/Viton 30/50/18/2</td>
<td>3.30</td>
<td>39 25 145 13 25 16 93 9 0.17 0.27</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Mg/NaNO₃/SA/Viton 40/40/18/2</td>
<td>3.90</td>
<td>54 35 211 21 32 20 123 13 0.17 0.25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Mg/NaNO₃/SA/Viton 50/30/18/2</td>
<td>3.80</td>
<td>77 47 252 26 46 28 153 16 0.19 0.30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Mg/NaNO₃/SA/Viton 60/20/18/2</td>
<td>3.40</td>
<td>153 95 260 27 115 44 185 20 0.37 0.59</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3.34: Peak Position and Peak Intensity Values of Succinic Anhydride Based Compositions

<table>
<thead>
<tr>
<th>Sr.No.</th>
<th>Composition Mg/NaNO₃/SA/Viton</th>
<th>Peak Position</th>
<th>Peak Intensity</th>
<th>Peak Position</th>
<th>Peak Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10/70/18/2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>20/60/18/2</td>
<td>2.7</td>
<td>21</td>
<td>4.3</td>
<td>55</td>
</tr>
<tr>
<td>3</td>
<td>30/50/18/2</td>
<td>2.7</td>
<td>60</td>
<td>4.3</td>
<td>113</td>
</tr>
<tr>
<td>4</td>
<td>40/40/18/2</td>
<td>2.7</td>
<td>95</td>
<td>4.3</td>
<td>368</td>
</tr>
<tr>
<td>5</td>
<td>50/30/18/2</td>
<td>2.7</td>
<td>77</td>
<td>4.3</td>
<td>296</td>
</tr>
<tr>
<td>6</td>
<td>60/20/18/2</td>
<td>2.7</td>
<td>105</td>
<td>4.3</td>
<td>227</td>
</tr>
</tbody>
</table>
Fig. 3.96 IR intensity of Mg/NaNO$_3$/SA/Viton (10/70/18/2) in 2-3 μm wave band

Fig. 3.97 IR intensity of Mg/NaNO$_3$/SA/Viton (10/70/18/2) in 3-5 μm wave band

Fig. 3.98 IR intensity of Mg/NaNO$_3$/SA/Viton (20/60/18/2) in 2-3 μm wave band
Fig. 3.99 IR intensity of Mg/NaNO₃/SA/Viton (20/60/18/2) in 3-5 µm wave band

Fig. 3.100 IR intensity of Mg/NaNO₃/SA/Viton (30/50/18/2) in 2-3 µm wave band

Fig. 3.101 IR intensity of Mg/NaNO₃/SA/Viton (30/50/18/2) in 3-5 µm wave band
Fig. 3.102 IR intensity of Mg/NaNO₃/SA/Viton (40/40/18/2) in 2-3 μm wave band

Fig. 3.103 IR intensity of Mg/NaNO₃/SA/Viton (40/40/18/2) in 3-5 μm wave band

Fig. 3.104 IR intensity of Mg/NaNO₃/SA/Viton (50/30/18/2) in 2-3 μm wave band
Fig. 3.105 IR intensity of Mg/NaNO₃/SA/Viton (50/30/18/2) in 3-5 µm wave band

Fig. 3.106 IR intensity of Mg/NaNO₃/SA/Viton (60/20/18/2) in 2-3 µm wave band

Fig. 3.107 IR intensity of Mg/NaNO₃/SA/Viton (60/20/18/2) in 3-5 µm wave band
Fig. 3.108  IR Spectral Graph of Mg/ NaNO₃/SA/Viton (10/70/18/2)

Fig. 3.109  IR Spectral Graph of Mg/ NaNO₃/SA/Viton (20/60/18/2)

Fig. 3.110  IR Spectral Graph of Mg/ NaNO₃/SA/Viton (30/50/18/2)
Fig. 111 IR Spectral Graph of Mg/NaNO₃/SA/Viton (40/40/18/2)

Fig. 112 IR Spectral Graph of Mg/NaNO₃/SA/Viton (50/30/18/2)

Fig. 113 IR Spectral Graph of Mg/NaNO₃/SA/Viton (60/20/18/2)
3.3.3 Benzene Tetra Carboxylic Di Anhydride (BTDA) based Compositions

The results obtained for BTDA based compositions are discussed in this subsection.

i. Sensitivity Data

Sensitivity results of the compositions bring out that BTDA based compositions are relatively safer compared to SA based compositions (table 3.35)

ii. Combustion Characteristics

Trends obtained for cal val values are also similar to those of PA and SA compositions. In anaerobic and aerobic condition thermo chemical data bring out similar pattern as for SA based compositions (table 3.36 - 3.37).

iii. Burn Rate and IR Intensity data in Different Wave bands

Burn rate and IR intensity data obtained during this work also follow similar trend as SA based compositions (table 3.38 & fig 3.114-3.125). IR intensity curves of SA based compositions in spectral mode show a strong peak emission at 4.0 – 5.0 µm similar to PA & SA based compositions (table 3.39 & fig 3.126 - 3.131).
### Table 3.35. Sensitivity Data of BTDA based compositions

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Composition Mg/NaNO₃/ BTDA /Viton</th>
<th>FOI</th>
<th>Friction Insensitive (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10/70/18/2</td>
<td>79</td>
<td>36</td>
</tr>
<tr>
<td>2</td>
<td>20/60/18/2</td>
<td>78</td>
<td>36</td>
</tr>
<tr>
<td>3</td>
<td>30/50/18/2</td>
<td>82</td>
<td>36</td>
</tr>
<tr>
<td>4</td>
<td>40/40/18/2</td>
<td>93</td>
<td>36</td>
</tr>
<tr>
<td>5</td>
<td>50/30/18/2</td>
<td>123</td>
<td>36</td>
</tr>
<tr>
<td>6</td>
<td>60/20/18/2</td>
<td>141</td>
<td>36</td>
</tr>
</tbody>
</table>

### Table 3.36. Temperature, Combustion Products and cal val Data of BTDA based compositions

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Composition Mg/NaNO₃/BTDA/Viton</th>
<th>cal val (cal/g)</th>
<th>Temp. (K)</th>
<th>CO (mol/kg)</th>
<th>C (c) (mol/kg)</th>
<th>CO₂ (mol/kg)</th>
<th>H₂O (mol/kg)</th>
<th>MgO (c) (mol/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10/70/18/2</td>
<td>860</td>
<td>2013</td>
<td>0.03</td>
<td>-</td>
<td>7.33</td>
<td>0.11</td>
<td>04.11</td>
</tr>
<tr>
<td>2</td>
<td>20/60/18/2</td>
<td>1235</td>
<td>2685</td>
<td>2.71</td>
<td>-</td>
<td>6.00</td>
<td>0.53</td>
<td>08.16</td>
</tr>
<tr>
<td>3</td>
<td>30/50/18/2</td>
<td>1582</td>
<td>2965</td>
<td>6.78</td>
<td>-</td>
<td>1.93</td>
<td>0.36</td>
<td>10.27</td>
</tr>
<tr>
<td>4</td>
<td>40/40/18/2</td>
<td>1423</td>
<td>2595</td>
<td>8.66</td>
<td>-</td>
<td>0.05</td>
<td>0.02</td>
<td>10.23</td>
</tr>
<tr>
<td>5</td>
<td>50/30/18/2</td>
<td>1360</td>
<td>1995</td>
<td>6.09</td>
<td>2.59</td>
<td>0.00</td>
<td>0.00</td>
<td>09.44</td>
</tr>
<tr>
<td>6</td>
<td>60/20/18/2</td>
<td>1300</td>
<td>1964</td>
<td>2.11</td>
<td>6.58</td>
<td>0.00</td>
<td>0.00</td>
<td>09.80</td>
</tr>
</tbody>
</table>
Table 3.37: Combustion Temperature and Combustion products of Mg/NaNO₃/BTDA/Viton (30/50/18/2) Composition in Aerobic condition

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Oxygen (Parts)</th>
<th>Temp. (K)</th>
<th>CO (mol/kg)</th>
<th>CO₂ (mol/kg)</th>
<th>H₂O (mol/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>3038</td>
<td>4.66</td>
<td>3.27</td>
<td>0.33</td>
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<tr>
<td>2</td>
<td>20</td>
<td>3032</td>
<td>3.56</td>
<td>3.71</td>
<td>0.30</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>3010</td>
<td>2.82</td>
<td>3.88</td>
<td>0.27</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
<td>2983</td>
<td>2.28</td>
<td>3.95</td>
<td>0.26</td>
</tr>
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<td>5</td>
<td>50</td>
<td>2951</td>
<td>1.85</td>
<td>3.96</td>
<td>0.24</td>
</tr>
</tbody>
</table>

Table 3.38: Burn Rate, IR Intensity and IR Efficiency Data of BTDA Based Compositions

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Composition Mg/NaNO₃/BTDA/Viton</th>
<th>LBR (mm/s)</th>
<th>IR Intensity (W/sr)</th>
<th>IR Efficiency (W.s/sr.g)</th>
<th>Φ 2-3/3-5</th>
<th>Φ 1.1-2.5/3-5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.1-2.5 µm</td>
<td>2-3 µm</td>
<td>3-5 µm</td>
<td>8-13 µm</td>
</tr>
<tr>
<td>1</td>
<td>10/70/18/2</td>
<td>1.2</td>
<td>25</td>
<td>16</td>
<td>42</td>
<td>7</td>
</tr>
<tr>
<td>2</td>
<td>20/60/18/2</td>
<td>3.0</td>
<td>35</td>
<td>21</td>
<td>92</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>30/50/18/2</td>
<td>4.7</td>
<td>63</td>
<td>38</td>
<td>202</td>
<td>20</td>
</tr>
<tr>
<td>4</td>
<td>40/40/18/2</td>
<td>6.8</td>
<td>116</td>
<td>75</td>
<td>439</td>
<td>37</td>
</tr>
<tr>
<td>5</td>
<td>50/30/18/2</td>
<td>8.2</td>
<td>236</td>
<td>126</td>
<td>663</td>
<td>56</td>
</tr>
<tr>
<td>6</td>
<td>60/20/18/2</td>
<td>7.0</td>
<td>425</td>
<td>224</td>
<td>540</td>
<td>61</td>
</tr>
</tbody>
</table>
Table 3.39: Peak Position and Peak Intensity Values of BTDA Based Compositions

<table>
<thead>
<tr>
<th>Sr.No.</th>
<th>Composition Mg/NaNO₃/BTDA/Viton</th>
<th>Peak Position (µm)</th>
<th>Peak Intensity (W/sr)</th>
<th>Peak Position (µm)</th>
<th>Peak Intensity (W/sr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10/70/18/2</td>
<td>2.7</td>
<td>76</td>
<td>4.3</td>
<td>155</td>
</tr>
<tr>
<td>2</td>
<td>20/60/18/2</td>
<td>2.7</td>
<td>35</td>
<td>4.3</td>
<td>130</td>
</tr>
<tr>
<td>3</td>
<td>30/50/18/2</td>
<td>2.7</td>
<td>66</td>
<td>4.3</td>
<td>315</td>
</tr>
<tr>
<td>4</td>
<td>40/40/18/2</td>
<td>2.7</td>
<td>75</td>
<td>4.3</td>
<td>520</td>
</tr>
<tr>
<td>5</td>
<td>50/30/18/2</td>
<td>2.7</td>
<td>190</td>
<td>4.3</td>
<td>825</td>
</tr>
<tr>
<td>6</td>
<td>60/20/18/2</td>
<td>2.7</td>
<td>210</td>
<td>4.3</td>
<td>500</td>
</tr>
</tbody>
</table>
Fig. 3.114 IR intensity of Mg/NaNO₃/BTDA/Viton (10/70/18/2) in 2-3 µm wave band

Fig. 3.115 IR intensity of Mg/NaNO₃/BTDA/Viton (10/70/18/2) in 3-5 µm wave band
Fig. 3.116 IR intensity of Mg/NaNO₃/BTDA/Viton (20/60/18/2) in 2-3 µm wave band

Fig. 3.117 IR intensity of Mg/NaNO₃/BTDA/Viton (20/60/18/2) in 3-5 µm wave band

Fig. 3.118 IR intensity of Mg/NaNO₃/BTDA/Viton (30/50/18/2) in 2-3 µm wave band
Fig. 3.119 IR intensity of Mg/NaNO₃/BTDA/Viton (30/50/18/2) in 3-5 μm wave band
Fig. 3.120 IR intensity of Mg/NaNO₃/BTDA/Viton (40/40/18/2) in 2-3 µm wave band

Fig. 3.121 IR intensity of Mg/NaNO₃/BTDA/Viton (40/40/18/2) in 3-5 µm wave band

Fig. 3.122 IR intensity of Mg/NaNO₃/BTDA/Viton (50/30/18/2) in 2-3 µm wave band
Fig. 3.123 IR intensity of Mg/NaNO₃/BTDA/Viton (50/30/18/2) in 3-5 µm wave band

Fig. 3.124 IR intensity of Mg/NaNO₃/BTDA/Viton (60/20/18/2) in 3-5 µm wave band

Fig. 3.125 IR intensity of Mg/NaNO₃/BTDA/Viton (60/20/18/2) in 3-5 µm wave band
Fig. 3.126 IR Spectral Graph of Mg/NaNO₃/BTDA/Viton (10/70/18/2)

Fig. 3.127 IR Spectral Graph of Mg/NaNO₃/BTDA/Viton (20/60/18/2)

Fig. 3.128 IR Spectral Graph of Mg/NaNO₃/BTDA/Viton (30/50/18/2)
Fig. 3.129 IR Spectral Graph of Mg/NaNO₃/BTDA/Viton (40/40/18/2)

Fig. 3.130 IR Spectral Graph of Mg/NaNO₃/BTDA/Viton (50/30/18/2)

Fig. 3.131 IR Spectral Graph of Mg/NaNO₃/BTDA/Viton (60/20/18/2)
3.3.4 Magnesium/Sodium nitrate/ Benzo Phenone Tetra Carboxylic Di Anhydride (BPTA) Based Compositions.

The results obtained for BPTA based Compositions are discussed in this subsection.

i. **Sensitivity Data**

The figure of insensitivity of the compositions ranges from 53 - 79 shows that these are relatively sensitive than even SA based compositions and more close to MTV. All the compositions are found friction insensitive up to 36 kg (table 3.40).

ii. **Combustion Characteristics**

Calorimetric data of the compositions are given in table 3.41. It increases with magnesium content (up to 30 %).

Thermo chemical data of BPTA based compositions follows similar trend as in case of PA based compositions (table 3.41 - 3.42) as in case of other POCF compositions.

iii. **Burn Rate and IR Intensity Data in Different Wave bands**

Burn rate is maximum at 40 % magnesium content unlike other POCF based compositions. IR intensity and IR efficiency results reveals that BPTA based compositions follow similar trend as in case of other anhydride based compositions. However, IR Spectral ratio $\Phi$ 2-3/3-5 is minimum at 20 % magnesium beyond that it increases. Spectral ratio of BPTA based promising composition is less than the standard MTV composition but more than other anhydride based compositions (table 3.43 & fig3.132-143).

The IR intensity curve of BPTA base composition in spectral mode is presented in fig 3.144 -3.149. BPTA Based composition shows 70 to 100 % peak intensity at 4.3 µm and 0 to 30 % peak intensity at 2.7 µm (table 3.44).
### Table 3.340. Sensitivity Data of BPTA based compositions

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Composition Mg/NaNO₃/BPTA/Viton</th>
<th>FOI</th>
<th>Friction Insensitive (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10/70/18/2</td>
<td>53</td>
<td>36</td>
</tr>
<tr>
<td>2</td>
<td>20/60/18/2</td>
<td>53</td>
<td>36</td>
</tr>
<tr>
<td>3</td>
<td>30/50/18/2</td>
<td>55</td>
<td>36</td>
</tr>
<tr>
<td>4</td>
<td>40/40/18/2</td>
<td>64</td>
<td>36</td>
</tr>
<tr>
<td>5</td>
<td>50/30/18/2</td>
<td>66</td>
<td>36</td>
</tr>
<tr>
<td>6</td>
<td>60/20/18/2</td>
<td>79</td>
<td>36</td>
</tr>
</tbody>
</table>

### Table 3.41. Temperature, Combustion Products and cal val Data of BPTA based compositions

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Composition Mg/NaNO₃/BPTA/Viton</th>
<th>cal.val (cal/g)</th>
<th>Temp. (K)</th>
<th>CO (mol/kg)</th>
<th>C (c) (mol/kg)</th>
<th>CO₂ (mol/kg)</th>
<th>H₂O (mol/kg)</th>
<th>MgO (c) (mol/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10/70/18/2</td>
<td>990</td>
<td>2004</td>
<td>0.079</td>
<td>-</td>
<td>9.76</td>
<td>0.38</td>
<td>4.11</td>
</tr>
<tr>
<td>2</td>
<td>20/60/18/2</td>
<td>1248</td>
<td>2688</td>
<td>5.18</td>
<td>-</td>
<td>4.77</td>
<td>1.17</td>
<td>8.08</td>
</tr>
<tr>
<td>3</td>
<td>30/50/18/2</td>
<td>1610</td>
<td>2792</td>
<td>9.24</td>
<td>-</td>
<td>0.71</td>
<td>0.48</td>
<td>10.08</td>
</tr>
<tr>
<td>4</td>
<td>40/40/18/2</td>
<td>1590</td>
<td>1986</td>
<td>9.07</td>
<td>0.84</td>
<td>-</td>
<td>-</td>
<td>8.94</td>
</tr>
<tr>
<td>5</td>
<td>50/30/18/2</td>
<td>1372</td>
<td>1986</td>
<td>5.03</td>
<td>4.89</td>
<td>-</td>
<td>-</td>
<td>9.46</td>
</tr>
<tr>
<td>6</td>
<td>60/20/18/2</td>
<td>1280</td>
<td>1931</td>
<td>1.10</td>
<td>8.83</td>
<td>-</td>
<td>-</td>
<td>9.86</td>
</tr>
</tbody>
</table>
Table 3.42: Combustion Temperature and Combustion products of Mg/ NaNO₃/ BPTA/ Viton (30/50/18/2) Composition in Aerobic condition

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Oxygen (Parts)</th>
<th>Temp. (K)</th>
<th>CO (mol/kg)</th>
<th>CO₂ (mol/kg)</th>
<th>H₂O (mol/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>3023</td>
<td>6.09</td>
<td>2.97</td>
<td>0.75</td>
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<tr>
<td>2</td>
<td>20</td>
<td>3042</td>
<td>4.60</td>
<td>3.70</td>
<td>0.69</td>
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<tr>
<td>3</td>
<td>30</td>
<td>3032</td>
<td>3.66</td>
<td>4.00</td>
<td>0.64</td>
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<tr>
<td>4</td>
<td>40</td>
<td>3012</td>
<td>2.98</td>
<td>4.13</td>
<td>0.60</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
<td>2988</td>
<td>2.47</td>
<td>4.18</td>
<td>0.57</td>
</tr>
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</table>
Table 3.43. Burn Rate, IR Intensity and IR Efficiency Data of BPTA based compositions

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Composition Mg/NaNO₃/BPTA/Viton</th>
<th>LBR (mm/s)</th>
<th>IR Intensity</th>
<th>IR Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.1-2.5 μm</td>
<td>2-3 μm</td>
</tr>
<tr>
<td>1</td>
<td>10/70/18/2</td>
<td>1.4</td>
<td>23 (W/sr)</td>
<td>17 (W/sr)</td>
</tr>
<tr>
<td>2</td>
<td>20/60/18/2</td>
<td>3.4</td>
<td>33 (W/sr)</td>
<td>27 (W/sr)</td>
</tr>
<tr>
<td>3</td>
<td>30/50/18/2</td>
<td>4.1</td>
<td>62 (W/sr)</td>
<td>53 (W/sr)</td>
</tr>
<tr>
<td>4</td>
<td>40/40/18/2</td>
<td>5.2</td>
<td>131 (W/sr)</td>
<td>103 (W/sr)</td>
</tr>
<tr>
<td>5</td>
<td>50/30/18/2</td>
<td>4.9</td>
<td>211 (W/sr)</td>
<td>159 (W/sr)</td>
</tr>
<tr>
<td>6</td>
<td>60/20/18/2</td>
<td>4.8</td>
<td>256 (W/sr)</td>
<td>216 (W/sr)</td>
</tr>
</tbody>
</table>
### Table 3.44: Peak Position and Peak Intensity Values of BPTA Based Compositions

<table>
<thead>
<tr>
<th>Sr.No.</th>
<th>Composition Mg/NaNO₃/BPTA/Viton</th>
<th>Peak Position µm</th>
<th>Peak Intensity W/sr</th>
<th>Peak Position µm</th>
<th>Peak Intensity W/sr</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10/70/18/2</td>
<td>-</td>
<td>-</td>
<td>4.3</td>
<td>65</td>
</tr>
<tr>
<td>2</td>
<td>20/60/18/2</td>
<td>2.7</td>
<td>50</td>
<td>4.3</td>
<td>425</td>
</tr>
<tr>
<td>3</td>
<td>30/50/18/2</td>
<td>2.7</td>
<td>60</td>
<td>4.3</td>
<td>460</td>
</tr>
<tr>
<td>4</td>
<td>40/40/18/2</td>
<td>2.7</td>
<td>80</td>
<td>4.3</td>
<td>560</td>
</tr>
<tr>
<td>5</td>
<td>50/30/18/2</td>
<td>2.7</td>
<td>75</td>
<td>4.3</td>
<td>500</td>
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<tr>
<td>6</td>
<td>60/20/18/2</td>
<td>2.7</td>
<td>150</td>
<td>4.3</td>
<td>310</td>
</tr>
</tbody>
</table>
Fig. 3.132 IR intensity of Mg/NaNO₃/BPTA/Viton (10/70/18/2) in 2-3 µm wave band

Fig. 3.133 IR intensity of Mg/NaNO₃/BPTA/Viton (10/70/18/2) in 3-5 µm wave band

Fig. 3.134 IR intensity of Mg/NaNO₃/BPTA/Viton (20/60/18/2) in 2-3 µm wave band
Fig. 3.135 IR intensity of Mg/NaNO₃/BPTA/Viton (20/60/18/2) in 3-5 µm wave band

Fig. 3.136 IR intensity of Mg/NaNO₃/BPTA/Viton (30/50/18/2) in 2-3 µm wave band

Fig. 3.137 IR intensity of Mg/NaNO₃/BPTA/Viton (30/50/18/2) in 3-5 µm wave band
Fig. 3.138 IR intensity of Mg/NaNO₃/BPTA/Viton (40/40/18/2) in 2-3 µm wave band

Fig. 3.139 IR intensity of Mg/NaNO₃/BPTA/Viton (40/40/18/2) in 3-5 µm wave band

Fig. 3.140 IR intensity of Mg/NaNO₃/BPTA/Viton (50/30/18/2) in 2-3 µm wave band
Fig. 3.141 IR intensity of Mg/NaNO₃/BPTA/Viton (50/30/18/2) in 3-5 µm wave band

Fig. 3.142 IR intensity of Mg/NaNO₃/BPTA/Viton (60/20/18/2) in 3-5 µm wave band

Fig. 3.143 IR intensity of Mg/NaNO₃/BPTA/Viton (60/20/18/2) in 3-5 µm wave band
Fig. 3.144 IR Spectral Graph of Mg/NaNO₃/BPTA/Viton (10/70/18/2)

Fig. 3.145 IR Spectral Graph of Mg/NaNO₃/BPTA/Viton (20/60/18/2)

Fig. 3.146 IR Spectral Graph of Mg/NaNO₃/BPTA/Viton (30/50/18/2)
Fig. 3.147 IR Spectral Graph of Mg/ NaNO₃/ BPTA /Viton (40/40/18/2)

Fig. 3.148 IR Spectral Graph of Mg/ NaNO₃/ BPTA /Viton (50/30/18/2)

Fig. 3.149 IR Spectral Graph of Mg/ NaNO₃/ BPTA /Viton (60/20/18/2)
3.3.5 Numerical correlation for the IR intensity prediction of Magnesium/Sodium nitrate/POCF Based Compositions

A numerical correlation is developed for the prediction of IR Intensity of POCF based compositions. The correlations obtained for different compositions are presented in table 3.45.

In Mg (x)/NaNO₃ (80-x)/PA (18)/Viton (2) composition, where x is varied in steps of 10 from 10 to 60. IR intensity is correlated with percentage Mg in the composition and various results are obtained by regression analysis for selected series of compositions. The correlation for 3-5 µm wave band is IR intensity = 20 x e (%Mg/20). Average values of wave length of different zones are considered for IR intensity (1.8 µm, 2.5 µm and 10.5 µm) correlation IR intensity = 20 x (WL)⁻⁰·₈₁₀⁹ x e (%Mg/20) is established.

Similarly a correlation relationship for IR intensity in different wave bands are generated for POCF compositions based on SA, BTDA and BPTA. These relationships can be used for prediction of IR intensity of POCF based compositions having different proportion of magnesium/NaNO₃.

Table 3.45. The Predicted IR Intensity Correlations of POCF Based Compositions

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Composition</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Composition</td>
<td>1.1-2.5 µm</td>
</tr>
<tr>
<td>1</td>
<td>Mg/NaNO₃/PA/Viton</td>
<td>20 x (WL)⁻⁰·₈₁₀⁹ x e (%Mg/20)</td>
</tr>
<tr>
<td>2</td>
<td>Mg/NaNO₃/SA/Viton</td>
<td>13.147 x(WL)⁻₀·₅₁₈₃ x e (%Mg/25)</td>
</tr>
<tr>
<td>3</td>
<td>Mg/NaNO₃/BTDA/Viton</td>
<td>13.9 x (WL)⁻₀·₄₄₅₆ x e (%Mg/18)</td>
</tr>
<tr>
<td>4</td>
<td>Mg/NaNO₃/BPTA/Viton</td>
<td>17 x (WL)⁻₀·₇ x e (%Mg/17)</td>
</tr>
</tbody>
</table>
3.3.7 Thermal analysis

As POCF based compositions gave promising results in terms of IR spectral ratio, thermal analysis of these compositions is also undertaken by applying DSC/TGA technique in nitrogen atmosphere at a heating rate of 10°C/min. Reference data is also generated for individual major ingredients magnesium, NaNO₃ as well as their mixtures with viton binder.

i. Magnesium

DSC/TGA curve of magnesium showed an exotherm with temperature maxima (T max) at 604°C with 52 % weight gain (fig 3.150). The temperature corresponds to ignition of magnesium powder. The weight gain indicates the reaction of magnesium with nitrogen forming magnesium nitride¹. The experimentally observed weight gain is less than the computed weight gain as Mg₃N₂ (138 %) probably due to incomplete conversion of magnesium to magnesium nitride.

ii. Sodium nitrate

Thermal analysis of sodium nitrate gave endotherms at Tmax of 275°C and 312°C (3.151). These endotherms may be attributed to crystal transformation and melting of sodium nitrate particles as reported by Freeman¹. Weight loss is observed (75%) during endothermic decomposition in the temperature range 600 - 850°C corresponding to loss of nitrogen and oxygen.

iii. POCF

DSC of phthalic anhydride, succinic anhydride, benzene tetracarboxylic dianhydride and benzophenone tetracarboxylic dianhydride show endothermic peaks at 130, 116, 263 and 216°C respectively corresponding to their melting points (fig 3.152-3.155).

vi Mg/NaNO₃ Composition

Thermal analysis of magnesium/NaNO₃ composition gave an endotherm at 310°C (Tmax) corresponds to melting of NaNO₃. Two exotherms are observed at 480°C
and 523°C (fig 3.156), first exotherm is accounted for the exothermic oxidation of magnesium by sodium nitrate decomposition products and second exotherm can be accounted for the total ignition of the sample. Relatively higher weight loss (70.25 %) is observed than the predicted weight loss may be due to fast reaction resulting in spillage of composition.

v. **Mg/NaNO₃/Viton composition:**

Mg/NaNO₃/Viton combination registered an endotherm at 304°C corresponding to melting temperature of sodium nitrate and one exotherm at 629.80°C which can be attributed to reaction of magnesium with decomposition products of NaNO₃ and viton. Relatively higher ignition temperature for Mg/NaNO₃/Viton composition than the Mg/NaNO₃ binary mixtures may be due to reduction in thermal conductivity of the composition because of coating of particle with viton. Weight loss observed during exothermic decomposition is close to Mg/NaNO₃ binary mixture (fig 3.157).

vi. **Mg/NaNO₃/POCF/Viton (30/50/18/2)**

All Mg/NaNO₃/POCF/Viton compositions exhibit one endotherm corresponding to melting of NaNO₃. PA, SA and BTDA compositions gave three exotherms at temperature lower than that in case of Mg/NaNO₃/Viton mix (fig 3.158, 3.159 & 3.162). It may be an outcome of greater extent of oxidative reaction of NaNO₃, POCF and magnesium. First and second exothermic peaks are observed at temperature even lower than that of Mg/NaNO₃ binary mix. BPTA composition gave single exotherm at 417 °C (fig 3.160). It may be due to high reactivity of phenone class of compounds.

vii. **Mg/NaNO₃/BTDA/Viton**

All Mg/NaNO₃/BTDA/Viton compositions exhibit endotherm corresponds to melting of NaNO₃ and gave three exotherms (fig 3.161 - 3.164). During the main exothermic reaction between the fuel and the oxidizer a sharp exothermic peak is observed between 463-559°C depending on the molar ratios of Mg/NaNO₃/BTDA/Viton. All the compositions show three stage weight loss. First stage loss ranges from 5 to 19 %, second stage loss is about 14 % and third stage is in the range of 2 to 27 %. Composition with 30 % magnesium shows maximum total weight loss about 62 %. It is also seen that
the increased magnesium content increases the net heat evolution in the exotherms up to 30% magnesium. Ignition temperature reduces on increasing magnesium content. 

**Fig 3.150. DSC-TGA of Magnesium**
Fig 3.151. DSC-TGA of Sodium nitrate

Peak at 130.10 °C
Area = 200.812 mJ
Delta H = 124.160 J/g

Fig 3.152 DSC of Phthalic Anhydride (PA)

Peak at 116.33 °C
Area = 344.423 mJ
Delta H = 177.571 J/g
Fig 3.153. DSC of Succinic Anhydride (SA)

Fig 3.154. DSC of Benzene Tetra carboxylic Dianhydride (BTDA)

Fig 3.155. DSC of Benzophenone Tetra carboxylic Dianhydride (BPTA)
Fig.3.156 DSC-TGA of Magnesium/Sodium nitrate (30/50 parts) composition

Fig. 3.157 DSC-TGA of Magnesium/Sodium nitrate/Viton (30/50/2 parts) composition
Fig. 3.158 DSC-TGA of Magnesium/Sodium nitrate/PA/Viton (30/50/18/2) composition

Fig. 3.159 DSC-TGA of Magnesium/Sodium nitrate/SA/Viton (30/50/18/2) composition
Fig. 3.160 DSC-TGA of Magnesium/Sodium nitrate/BPTA/Viton (30/50/18/2) composition

Fig. 3.161 DSC-TGA of Magnesium/Sodium nitrate/BTDA/Viton (20/60/18/2) composition
Fig.3.162 DSC-TGA of Magnesium/Sodium nitrate/BTDA/Viton (30/50/18/2) composition

Fig.3.163 DSC-TGA of Magnesium/Sodium nitrate/BTDA/Viton (40/40/18/2) composition
Fig. 3.164  DSC-TGA of Magnesium/Sodium nitrate/BTDA/Viton (50/30/18/2) composition

3.3.8 Combustion products Analysis

Gaseous combustion products of SA based compositions are analyzed by GC. An increase in volume of carbon dioxide is observed on increase in magnesium content upto 30 %. Further increase in magnesium led to reduction in CO$_2$ content in the combustion products. The chromatograms of the compositions are depicted in fig 3.165- 3.170.
Fig. 3.165 Chromatogram of Mg/NaNO₃/SA/Viton (10/70/18/2) composition

Fig. 3.166 Chromatogram of Mg/NaNO₃/SA/Viton (20/60/18/2) composition
Fig. 3.167 Chromatogram of Mg/NaNO₃/SA/Viton (30/50/18/2) composition

Fig. 3.168 Chromatogram of Mg/NaNO₃/SA/Viton (40/40/18/2) composition
Fig. 3.169 Chromatogram of Mg/NaNO₃/SA/Viton (50/30/18/2) composition

Fig. 3.170 Chromatogram of Mg/NaNO₃/SA/Viton (60/20/18/2) composition
3.3.9 General Discussions

The ranges of cal val, flame temperature and burn rate data obtained for the different types of compositions studied during this work are presented in table 3.46.

Present study brings out that reduction of sodium nitrate in HCCF compositions results in reduction of cal val and flame temperature (anaerobic). This may be attributed to decrease in extent of formation of MgO during combustion. Among HCCF based compositions, charcoal based compositions produce more heat output as well as high flame temperature which may be attributed to participation of its internal oxygen in combustion of composition.

In case of fluoro polymer based compositions (Mg/NaNO3/fluropolymers) cal val reduces and flame temperature increases on replacement of fluoro polymer by NaNO3 in the composition. Increase in cal val may be attributed to remarkable difference in the heat of formation of MgF2 (-1124.200 kJ/mol) and MgO (-601.500 kJ/mol). Heat of oxidation of magnesium with gaseous fluorine (-46.2 kJ/g Mg) is greater compared to heat of oxidation of magnesium with oxygen ( -24.8 kJ/g Mg). Increase in flame temperature on increase in NaNO3 content a replacement of fluoro polymer by NaNO3 may be attributed to heat losses due to vaporization of MgF2 in molten state (m.p.1534 K). MgO does not melt near the flame temperature of the composition (m.p.3105 K). Corresponding PTFE based compositions produce higher cal val and flame temperature compared to viton/KeL-F based compositions due to higher fluorine content of former.

Cal val and flame temperature of POCF based compositions increase on increase in magnesium content up to 30 % as replacement of NaNO3 and MgO formation is also high at 30 % magnesium (fig 3.171 - 3.172). It can be an outcome of realization of stoichiometry of the composition (40 - 46 % magnesium and 54 - 60 % NaNO3)\textsuperscript{4}

\[
\begin{align*}
6\text{Mg} + 2 \text{NaNO}_3 &\rightarrow 6\text{MgO} + 2\text{Na} + \text{N}_2 + 588.4 \text{ kcal (Mg/NaNO}_3 \text{ ratio 41.3/58.6)} \\
5\text{Mg} + 2 \text{NaNO}_3 &\rightarrow 5\text{MgO} + \text{Na}_2\text{O} + \text{N}_2 + 632.8 \text{ kcal (Mg/NaNO}_3 \text{ ratio 45.85/54.14)}
\end{align*}
\]
Fig. 3.171. Flame Temperature of POCF based compositions in Anaerobic condition as function of magnesium content

Fig. 3.172. Flame Temperature of POCF based compositions in Anaerobic condition as a function of MgO content.
The results can be correlated with the oxygen balance of POCF (OB: PA; -162.03 %, BPTA; -149.06, BTDA; -110.03 % & SA; -95.93 %). Although compositions based on POCF studied during this work exhibited almost similar cal val, SA and BTDA compositions gave higher flame temperature compared to BPTA and PA based compositions.

DSC-TGA studies carried out on Mg/NaNO₃/BDTA/Viton compositions. The composition containing 30 % magnesium gave maximum heat output.

The burn rate of HCCF based compositions studied during this work increase with increase in magnesium content. The thermal conductivity of the pyrotechnic mixture influences the burn rate due to significance role of preheating of the un-burnt composition and can be correlated with the metal content of the composition. Metals are the best thermal conductor, whereas organic compounds rank among the worst conductor. During combustion of fuel rich compositions in air, the excess fuel also undergoes oxidation in air resulting in increase in heat output results in high burn rate. Compositions incorporating graphite exhibited higher burn rate as compared to charcoal and anthracene based compositions. It may be due to high thermal conductivity of graphite (140 WK⁻¹m⁻¹). Graphite is widely used in pyrotechnic compositions to increase the thermal conductivity of a pyrotechnic composition.
Table 3.46. Cal val, Flame Temperature and Burn Rate Value Ranges for Different Compositions

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Carbon Source</th>
<th>cal val (cal/g)</th>
<th>Flame temperature (K)</th>
<th>Burn rate (mm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High Carbon Content Fuel</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Graphite</td>
<td>700 - 1110</td>
<td>1595 - 1885</td>
<td>7 - 18</td>
</tr>
<tr>
<td>2</td>
<td>Charcoal</td>
<td>1200 - 1400</td>
<td>1925 - 1940</td>
<td>3 - 7</td>
</tr>
<tr>
<td>3</td>
<td>Anthracene</td>
<td>775 - 1160</td>
<td>1540 - 1900</td>
<td>3 - 15</td>
</tr>
<tr>
<td></td>
<td>Fluro Polymers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>MTV</td>
<td>1185 - 1750</td>
<td>1535 - 2365</td>
<td>3 - 7</td>
</tr>
<tr>
<td>5</td>
<td>Teflon</td>
<td>1100 - 1485</td>
<td>1365 - 1690</td>
<td>5 - 28</td>
</tr>
<tr>
<td>6</td>
<td>Viton</td>
<td>1085 - 1350</td>
<td>1340 - 1580</td>
<td>8 - 11</td>
</tr>
<tr>
<td>7</td>
<td>KeL-F</td>
<td>1050 - 1385</td>
<td>1050 - 1520</td>
<td>6 - 11</td>
</tr>
<tr>
<td></td>
<td>Partially Oxidized Fuel</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>PA</td>
<td>835 - 1560</td>
<td>1920 - 2710</td>
<td>1 - 8</td>
</tr>
<tr>
<td>9</td>
<td>SA</td>
<td>1240 - 1525</td>
<td>1950 - 2900</td>
<td>1 - 4</td>
</tr>
<tr>
<td>10</td>
<td>BTDA</td>
<td>860 - 1580</td>
<td>1965 - 2965</td>
<td>1 - 8</td>
</tr>
<tr>
<td>11</td>
<td>BPTA</td>
<td>990 - 1610</td>
<td>1930 - 2790</td>
<td>1 - 5</td>
</tr>
</tbody>
</table>
Burn rate of fluoro polymers based compositions also increases with decrease in fluoro polymer content probably due to high thermal conductivity of composition. This trend may be correlated with thermal conductivity of fluropolymers used during this work (PTFE 0.024 WK\(^{-1}\)m\(^{-1}\), Viton 0.226 WK\(^{-1}\)m\(^{-1}\), KeLF 0.053 WK\(^{-1}\)m\(^{-1}\)). PTFE based composition gave higher burn rate compared to other fluoro polymer based compositions during this work. It may be due to high fluorine content of PTFE (76 % F) compared to viton (66 % F) and KeLF (50.6 % F). It may also be due to greater extent of porosity in the composition it does not act as binder unlike viton and KeL-F.

Burn rate of POCF compositions increases exponentially with increase in magnesium even beyond stoichiometry. These results are in line with those reported by Singh H et al\(^9,10\) for binary mixture of Mg/NaNO\(_3\). Miyata, K et al\(^11\) also reported similar findings for Ti/KNO\(_3\) and Zr/KNO\(_3\).

The ranges of IR efficiency and spectral data obtained for the different types of compositions studied during this work are presented in table 3.47. IR intensity and IR efficiency of promising compositions are depicted in fig. 3.173-3.178. Mg/NaNO\(_3\)/anthracene compositions exhibited higher IR efficiency compared to MTV composition in 3-5 µm wave band, where as graphite and charcoal gave lower efficiency. Higher efficiency obtained in case of anthracene based compositions among HCCF compositions may be attributed to the higher fineness and therefore higher surface area of freshly generated carbon from anthracene (in the flame) compared to the graphite/charcoal particles which is added in the composition.
<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Carbon Source</th>
<th>IR Efficiency 2-3 µm (W.s/sr.g)</th>
<th>IR Efficiency 3-5 µm (W.s/sr.g)</th>
<th>IR Spectral ratio $\Phi_{2-3/3-5}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>High Carbon Content Fuel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Graphite</td>
<td>40 - 60</td>
<td>100 - 150</td>
<td>0.38 - 0.44</td>
</tr>
<tr>
<td>2</td>
<td>Charcoal</td>
<td>70 - 80</td>
<td>100 - 190</td>
<td>0.34 - 0.42</td>
</tr>
<tr>
<td>3</td>
<td>Anthracene</td>
<td>340</td>
<td>240 - 565</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fluro Polymers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>MTV</td>
<td>225 - 280</td>
<td>300 - 380</td>
<td>0.67 - 0.87</td>
</tr>
<tr>
<td>5</td>
<td>Teflon</td>
<td>35 - 175</td>
<td>120 - 260</td>
<td>0.25 - 0.63</td>
</tr>
<tr>
<td>6</td>
<td>Viton</td>
<td>55 - 265</td>
<td>130 - 420</td>
<td>0.42 - 0.61</td>
</tr>
<tr>
<td>7</td>
<td>KeL-F</td>
<td>40 - 210</td>
<td>115 - 330</td>
<td>0.63 - 0.36</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Partially oxidized Fuel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>PA</td>
<td>20 - 40</td>
<td>55 - 100</td>
<td>0.31 - 0.60</td>
</tr>
<tr>
<td>9</td>
<td>SA</td>
<td>20 - 45</td>
<td>70 - 185</td>
<td>0.17 - 0.37</td>
</tr>
<tr>
<td>10</td>
<td>BTDA</td>
<td>15 - 70</td>
<td>60 - 175</td>
<td>0.17 - 0.41</td>
</tr>
<tr>
<td>11</td>
<td>BPTA</td>
<td>16 - 105</td>
<td>40 - 120</td>
<td>0.35 - 0.97</td>
</tr>
</tbody>
</table>
Fig.3.173. IR intensity data of promising HCCF based compositions

Fig.3.174 IR intensity data of promising Fluro polymer based compositions

Fig.3.175 IR intensity data of promising POCF based compositions
Fig.3.176 IR efficiency data of promising HCCF based compositions

Fig.3.177 IR efficiency data of promising Fluro polymer based compositions

Fig.3.178 IR efficiency data of promising POCF based compositions
As regards spectral ratio charcoal based compositions is found superior as it gives low IR spectral ratio ($\Phi_{2.3/3.5}$) among HCCF based compositions. It may be accounted for the low carbon content and high carbon monoxide in combustion products as predicted by REAL programme (fig 3.179).

![Graph showing Carbon Content of HCCF Based Compositions in Anaerobic Condition](image)

**Fig 3.179. Carbon Content of HCCF Based Compositions in Anaerobic Condition**

The oxygen balance is computed for the HCCF based compositions and results are presented in fig.3.180. The oxygen balance (OB) values indicates that HCCF compositions are fuel rich in nature. The charcoal compositions have better oxygen balance as compared to graphite compositions results in better IR spectral ratio.
In case of fluro polymers based compositions, desired low IR spectral ratio is observed for PTFE based compositions. It may be due to its lower carbon content (24%) compared to viton (32%) and KeL-F (23%) (fig.3.181).
Low IR spectral ratio is observed in SA and BTDA based compositions. IR intensity measurement in spectral mode of POCF based compositions reveals that, all compositions shows strong peak emission in 4.0 - 5.0 μm region. High spectral ratio for PA and BPTA based composition may be due to high black body radiation level resulting from higher carbon content. These results may also be explained on the basis of higher flame temperature of SA and BTDA. In each series of POCF based compositions, IR spectral ratio reduces with increase in flame temperature. Emission intensity of specific emitters (CO, CO₂ and H₂O) increases with increase in flame temperature as more and more molecules are vaporized and excited to higher energy level and emit IR emission at specific wave lengths on return to ground state.

Stoichiometric POCF compositions with optimum magnesium content having carbon free combustion products show lowest IR spectral ratio. On generation of carbon in the combustion products, the effect of specific emitters (CO, CO₂ and H₂O) is lost or diminished due to the effect of black body radiation from the carbon content resulting in increase in IR spectral ratio¹².

All the anhydrides have negative oxygen balance, oxygen balance increases in the order of PA (-162.03 %) < BPTA (-149.06 %) < BTDA (-110.03 %) < SA (-95.93 %). IR spectral ratio reduces with increase in oxygen balance. However, IR spectral ratio of BPTA based composition is marginally higher than the PA based composition. C/O ratio of a POCF plays very important role in achieving more IR intensity in 3-5 μm band as it determines the degree of conversion of carbon to CO/CO₂ in the primary combustion zone and oxygen in the vicinity of the aromatic ring alters the decomposition pathway and impedes soot formation¹³ Intermediary soot formation is inhibited by the high oxygen level as reported by Roth et al¹⁴. It has also been reported by Ebeoglu¹⁵ that an over-oxidized system gives rise to a large IR intensity in 3-5 μm wave band. For POCF based compositions CO is maximum at 30 % magnesium content (fig 3.182) and IR spectral ratio is also low at this point.
Fig 3.182. Carbon Monoxide Content of POCF based compositions in Anaerobic condition
4.3. References


