Supporting Information

Biomass Derived Sustainable Hypergolic Rocket Propellant with Hydrogen Peroxide

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Table of Contents

Materials Preparation and Synthesis

Coconut Husk (**CH**) **Powder**. To remove most of the unwanted impurities, small pieces of raw coconut husk (25.0 g) from a mature coconut were soaked with stirring in water (400 mL) for 15 min. Then, the stirring was stopped, leading to precipitation of heavier unwanted material. The desired coconut husk was floating at the upper part of the vessel and was separated by decantation from the unwanted precipitate. After the separation, the soaking-separation protocol was repeated, and the resulting coconut husk foam was added to hot water (400 mL, ~80 °C) and stirred for 1 hr. Then, the resulting washed coconut husk was air-dried and ground to powder using a mechanical grinder, and dry particles were sieved through a metal sieve (20 μm) to obtain a uniform **CH** powder of about 10-20 μm (~23.0 g).

NCH1 (compound obtained after **24 hours of nitration**). To a mixture of HNO_3 (30 mL, 70%) and H_2SO_4 (45 mL, 98%), **CH** powder (3.0 g) was added portion-wise at 0 °C. Then, the reaction mixture was stirred for 15 min. at this temperature, allowed to warm up to RT, and kept without stirring for **24 hrs**. After that time, the reaction mixture was poured into ice-cold water (250 mL), and the solid material was filtered under vacuum, washed with water (2 × 200 mL), aqueous $NaHCO_3$ (5 wt.%; 50 mL), and again with water (100 mL). The washed solid material was air dried to yield nitrated coconut husk (**NCH1**) as a yellow powder (1.29 g; Figure 1, main manuscript).

NCH2 (compound obtained after **2 days of nitration**). To a mixture of HNO_3 (30 mL, 70%) and H_2SO_4 (45 mL, 98%), **CH** powder (3.0 g) was added portion-wise at 0 °C. Then, the reaction mixture was stirred for 15 min. at this temperature, allowed to warm up to RT, and kept without stirring for **2 days**. After that time, the reaction mixture was poured into ice-cold water (250 mL), and the solid material was filtered under vacuum, washed with water (2 × 200 mL), aqueous $NaHCO_3$ (5 wt.%; 50 mL), and again with water (100 mL). The washed solid material was air dried to yield nitrated coconut husk (**NCH2**) as a yellow powder (1.36 g).

NCH3 (compound obtained after **3 days of nitration**). To a mixture of HNO_3 (30 mL, 70%) and H_2SO_4 (45 mL, 98%), **CH** powder (3.0 g) was added portion-wise at 0 °C. Then, the reaction mixture was stirred for 15 min. at this temperature, allowed to warm up to RT, and kept without stirring for **3 days**. After that time, the reaction mixture was poured into ice-cold water (250 mL), and the solid material was filtered under vacuum, washed with water (2 × 200 mL), aqueous $NaHCO_3$ (5 wt.%; 50 mL), and again with water (100 mL). The washed solid material was air dried to yield nitrated coconut husk (**NCH3**) as a yellow powder (1.50 g).

NCH4 (compound obtained after **4 days of nitration**). To a mixture of HNO_3 (30 mL, 70%) and H_2SO_4 (45 mL, 98%), **CH** powder (3.0 g) was added portion-wise at 0 °C. Then, the reaction mixture was stirred for 15 min. at this temperature, allowed to warm up to RT, and kept without stirring for **4 days**. After that time, the reaction mixture was poured into ice-cold water (250 mL), and the solid material was filtered under vacuum, washed with water (2 × 200 mL), aqueous $NaHCO_3$ (5 wt.%; 50 mL), and again with water (100 mL). The washed solid material was dried under air to yield nitrated coconut husk (**NCH4**) as a yellow powder (1.17 g).

Nitro-lignin Extraction from NCH4.

To a dried **NCH4** sample (500 mg) in a pressure tube, water (10 mL) and NaOH solution (10 mL, 13% w/v) were added. Then the reaction mixture was heated for 1 hour at 120°C. After completion of the reaction, the insoluble material was separated by centrifugation. The solution was acidified using aqueous H_2SO_4 (20%) until it reached pH 2. Then, the resultant solution was cooled to 0-5°C, allowing the formation of a precipitate. The precipitate was separated by centrifugation, washed with water (2 × 50 mL), and dried on a hot plate at 40°C for 12 hours to yield nitro-lignin (0.8 mg).

CH-extracted Cellulose. Extraction of cellulose from the **CH** was performed in two steps, which included delignification, followed by bleaching process. Delignification process facilitates the extraction of cellulose by breaking the bonds between lignin and cellulose. For delignification, powdered **CH** (5.0 g) was added portion wise to an aqueous NaOH solution (1.5 M, 100 mL) and refluxed for 90 minutes. Then, the solid residue was filtered under vacuum, washed with water until the filtrate was clear and air dried. After drying, the solid residue was subjected to a bleaching process, by its dispersion in a distilled water (100 mL), followed by addition of sodium chlorite (1.5 g), and dropwise addition of glacial acetic acid to maintain the pH of the mixture at 4.0. Subsequently, the reaction mixture was heated for one hour at 70 °C, vacuum filtered, and washed with water (2 × 100 mL). The bleaching process was repeated five times to yield cellulose, which appeared as an off-white colored solid (1.4 g).

CH-extracted Nitrocellulose (NC-CH). To a mixture of concentrated HNO_3 (6.0 mL, 70%) and H_2SO_4 (8.0 mL, 98%), CH-extracted cellulose (0.5 g) was added portion-wise at 0 °C. At the end of the addition, the reaction mixture was stirred for 15 min at 0-5 °C, allowed to warm up to RT and left for 4 days without stirring. After that time, the reaction mixture was poured into ice-cold water (50 mL), solid material was vacuum filtered and washed with water (2 × 50 mL). This material was further washed with aqueous $NaHCO_3$ (5.0 wt.%; 50 mL), to remove traces of acids. Then, it was washed with water (50 mL), and air dried to yield the desired **NC-CH** as yellow solid (445 mg).

Mn-GU Complex. To a suspension of guanine (500 mg, 3.3 mmol; 4.0 eq.) in water (20 mL), aqueous KOH (2.0 M, 4.0 mL; 2.5 eq.) was added dropwise at RT. Then, to the resulting suspension, aqueous solution of $MnCl_2{\cdot}4H_2O$ (164 mg, 0.83 mmol, 10 mL; 1.0 eq.) was added dropwise at RT leading to a formation of a grey precipitate. The reaction mixture was stirred at RT for an additional 3 days, and the formed precipitate was separated by centrifugation. The separated precipitate was further washed with water (3 × 40 mL), acetone (30 mL) (Figure S1), and then air dried to obtain **Mn-GU** complex as ash-grey solid product (167 mg, 49% yield). Elemental analysis: $C_{10}H_{14}N_{10}MnO_5$.

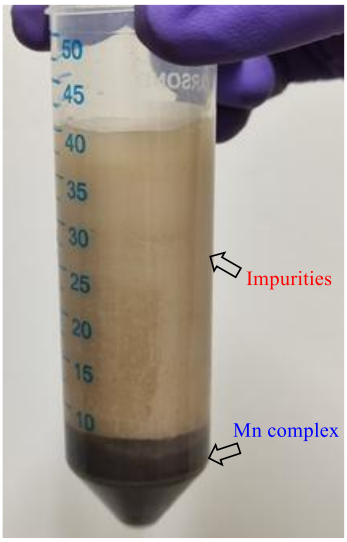


Figure S1. Image of **Mn-GU** complex (dark precipitate) during the separation-purification process.

Cu-GU Complex. To a suspension of guanine (500 mg, 3.3 mmol; 4.0 eq.) in water (20 mL), aqueous KOH (2.0 M, 4.0 mL; 2.5 eq.) was added dropwise at RT. Then, to the resulting suspension, aqueous solution of $CuCl_2 \cdot 2H_2O$ (141 mg, 0.83 mmol, 10 mL; 1 eq.) was added dropwise at RT leading to the formation of a dark olive-green colored solution. The reaction mixture was stirred at RT for an additional 3 days, the unreacted materials were separated by centrifugation, and the resulting solution of the product was filtered and air dried. The dried crude product was washed with CH_3OH (4 × 40 mL), acetone (30 mL), and air dried to obtain **Cu-GU** complex as a dark-olive green solid (220 mg, 63% yield). Elemental analysis: $C_{10}H_{14}N_{10}CuO_5$.

FT-IR Spectra

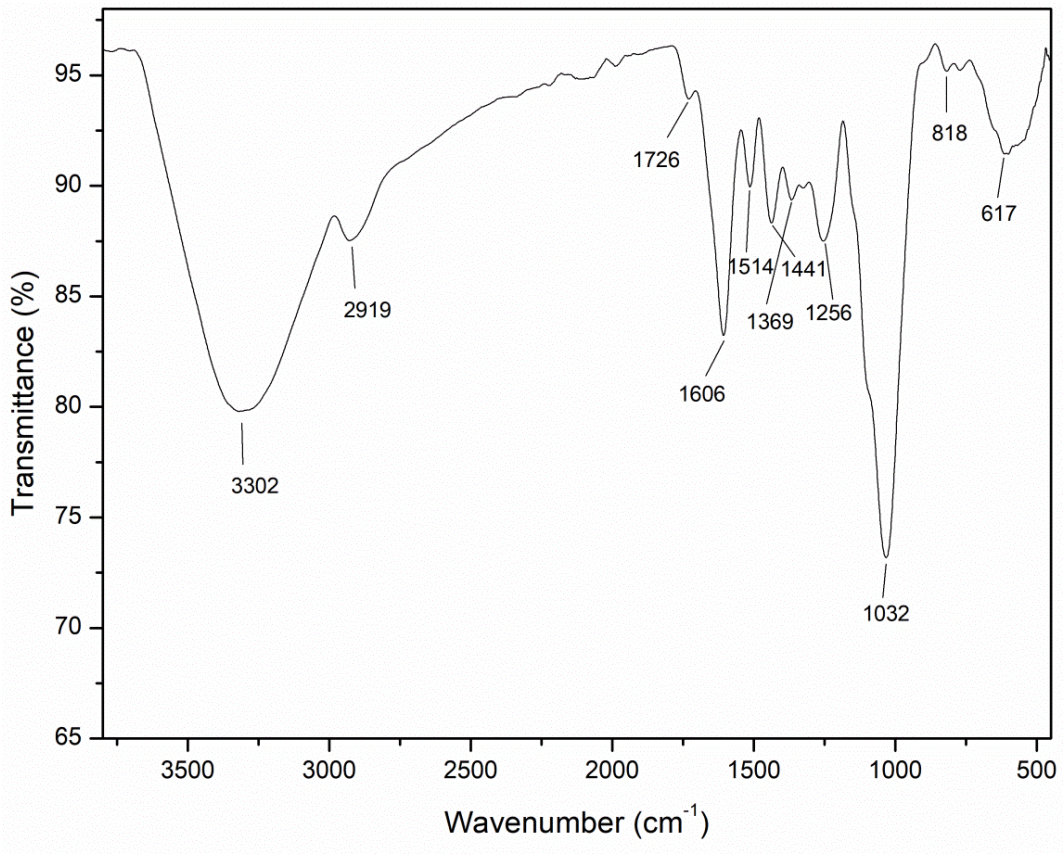


Figure S2. FT-IR spectrum of **CH**.

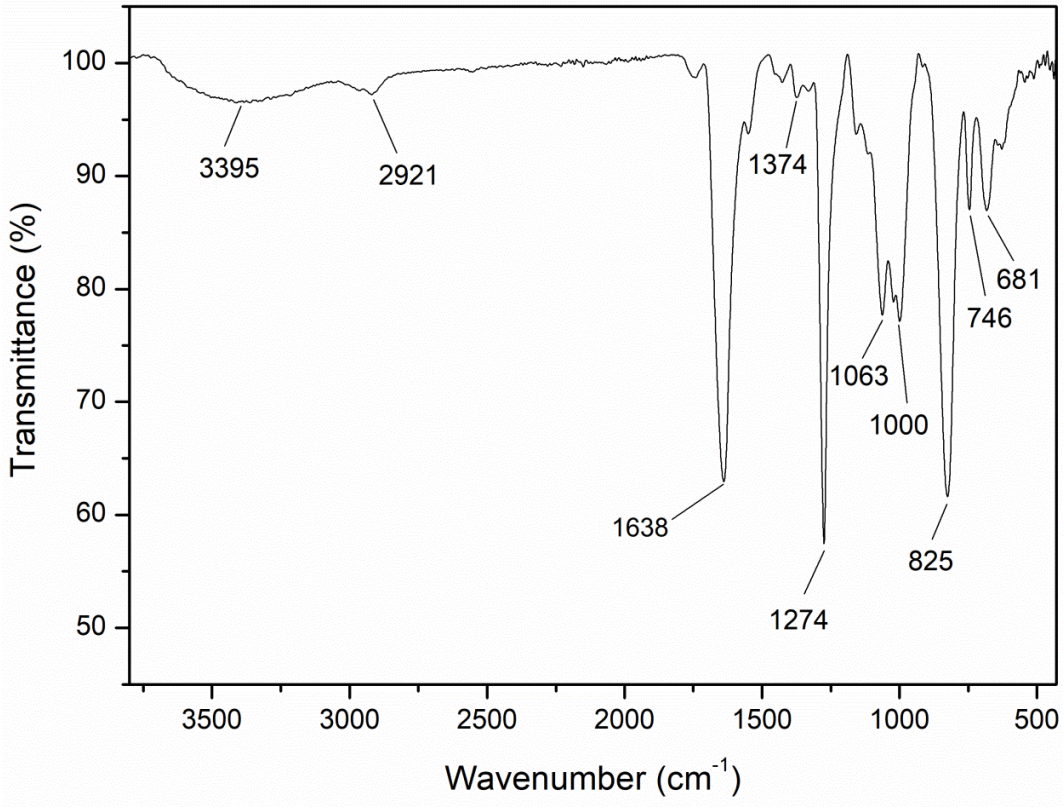


Figure S3. FT-IR spectrum of **NCH1.**

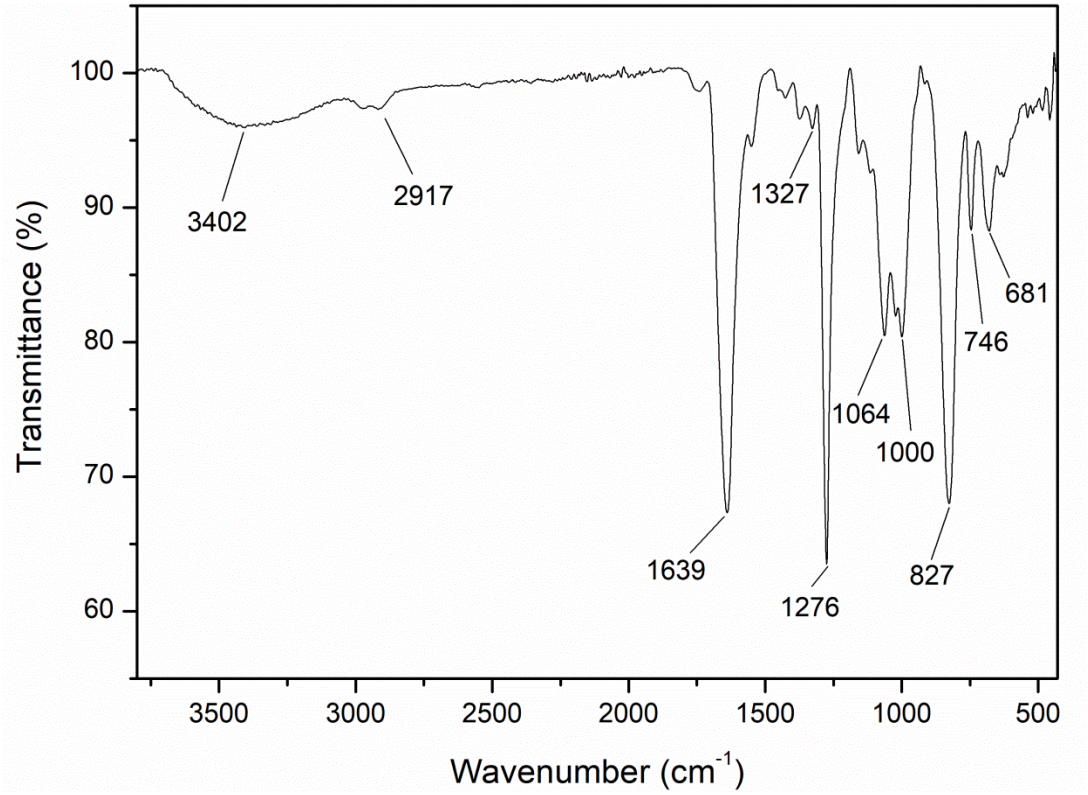


Figure S4. FT-IR spectrum of **NCH2**.

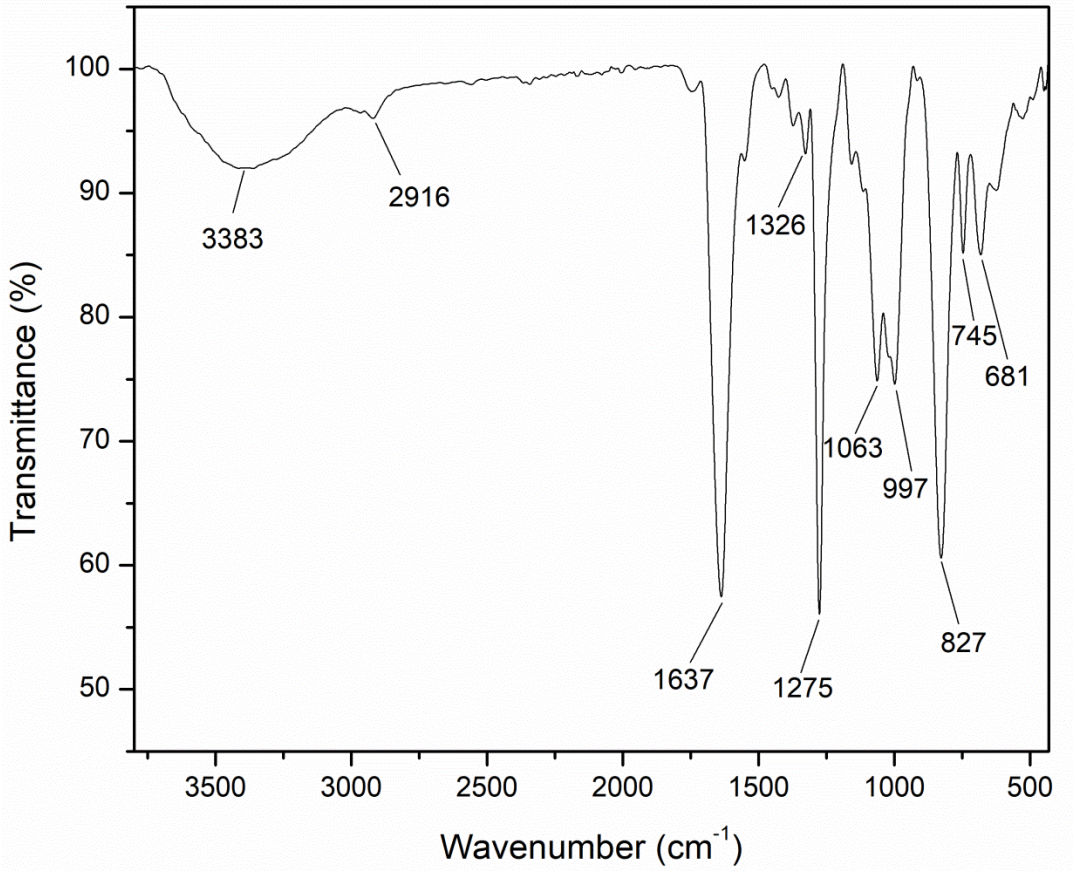


Figure S5. FT-IR spectrum of **NCH3**.

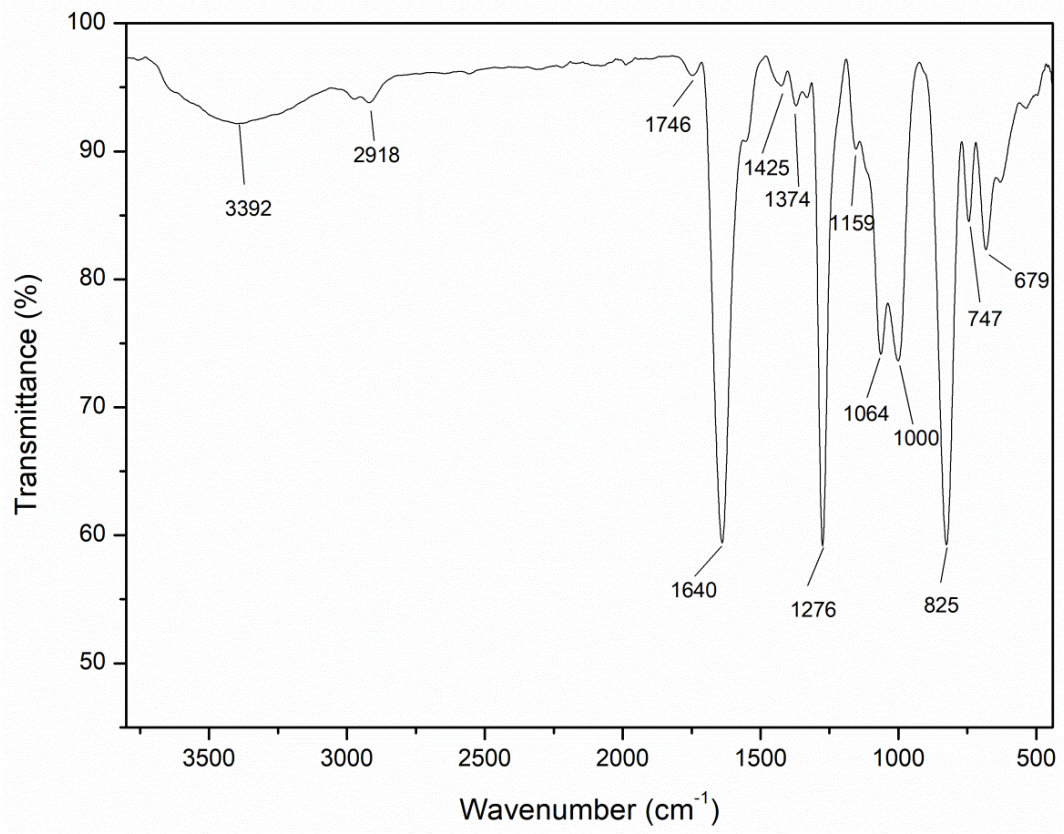


Figure S6. FT-IR spectrum of **NCH4**.

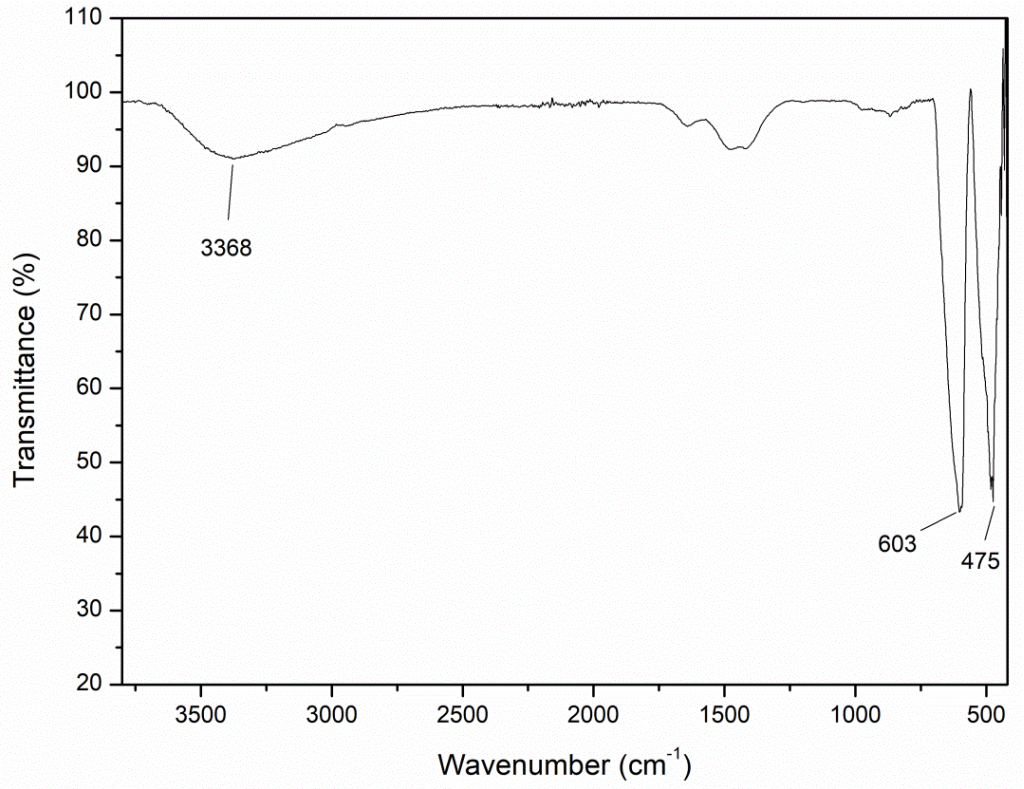


Figure S7. FT-IR spectrum of Mn_3O_4 precipitate.

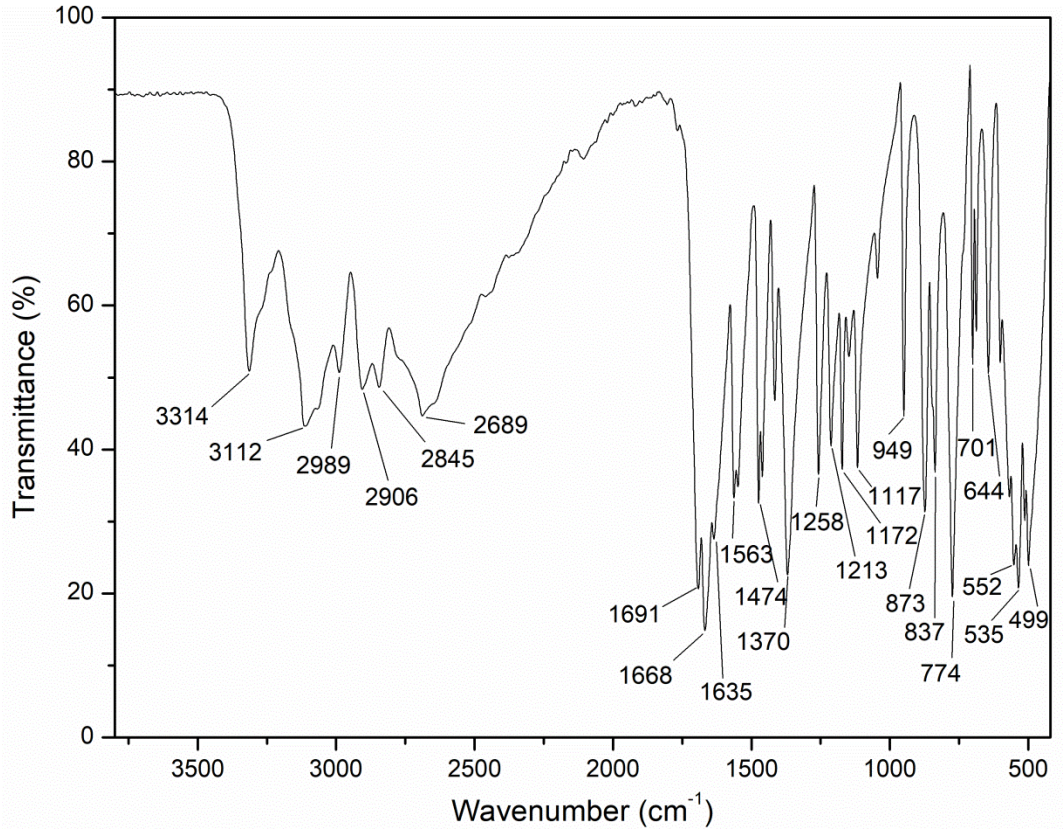


Figure S8. FT-IR spectrum of **GU**.

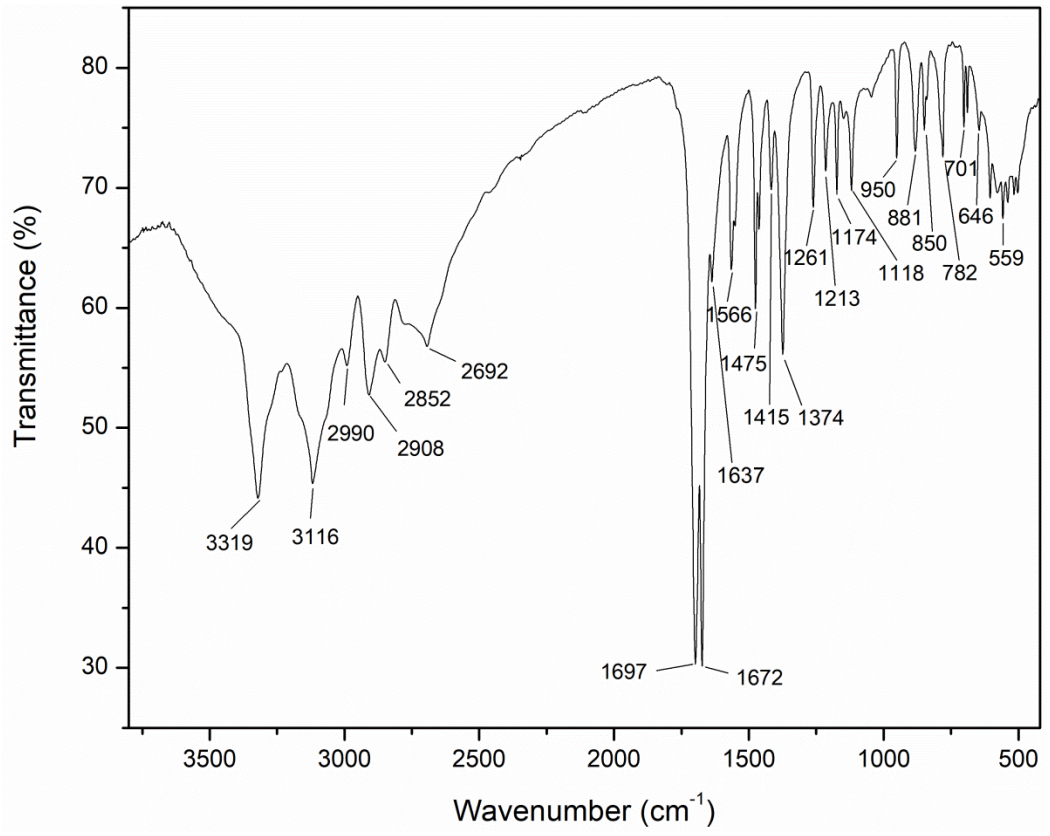


Figure S9. FT-IR spectrum of **Mn-GU** complex.

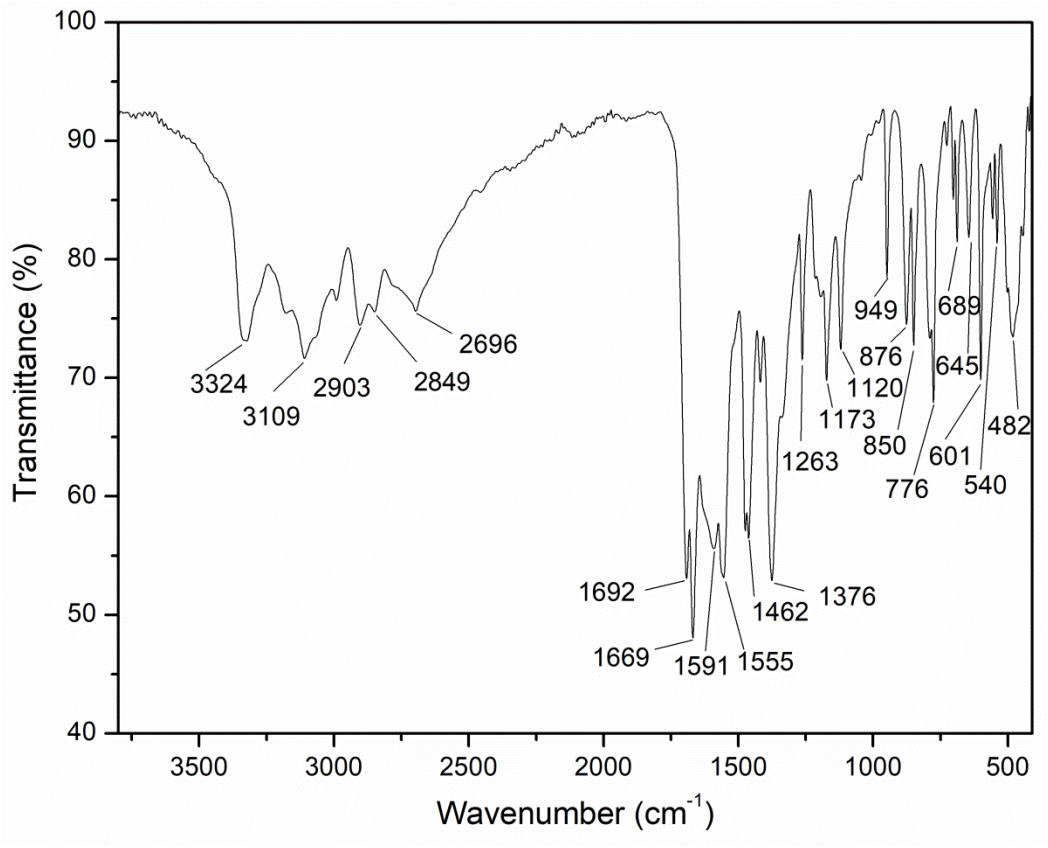


Figure S10. FT-IR spectrum of **Cu-GU** complex.

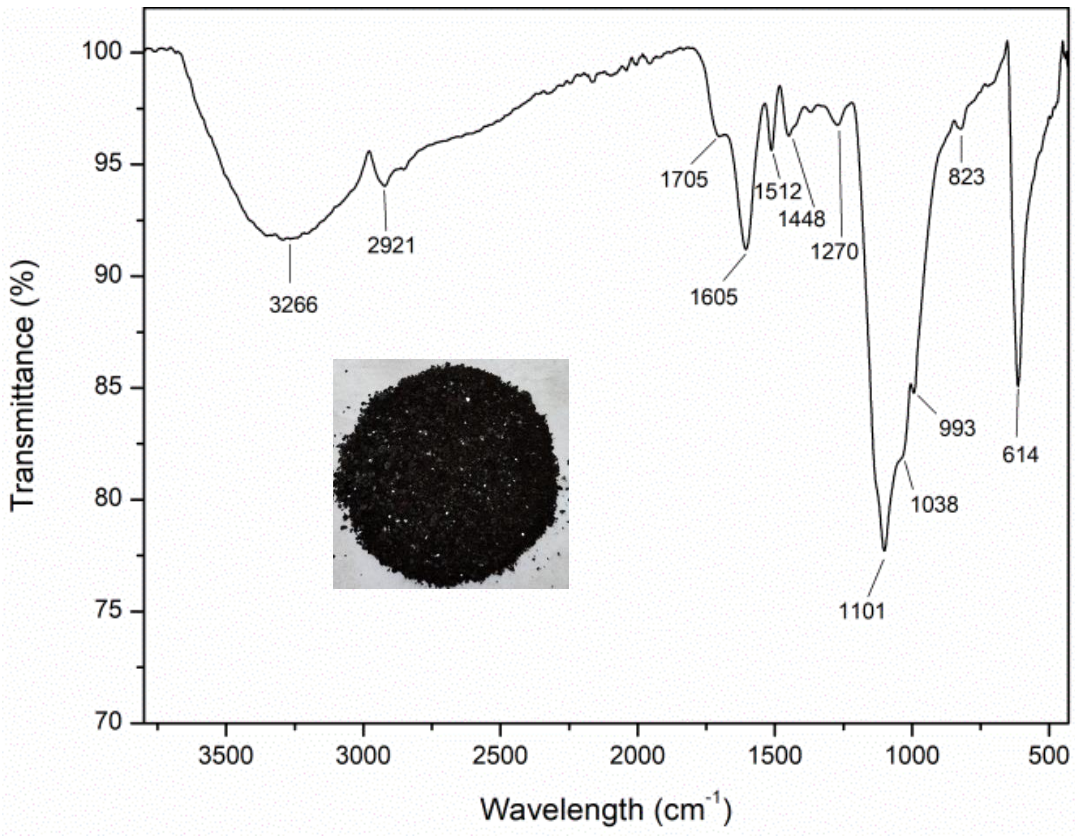


Figure S11. FT-IR spectrum of lignin extracted from coconut husk.

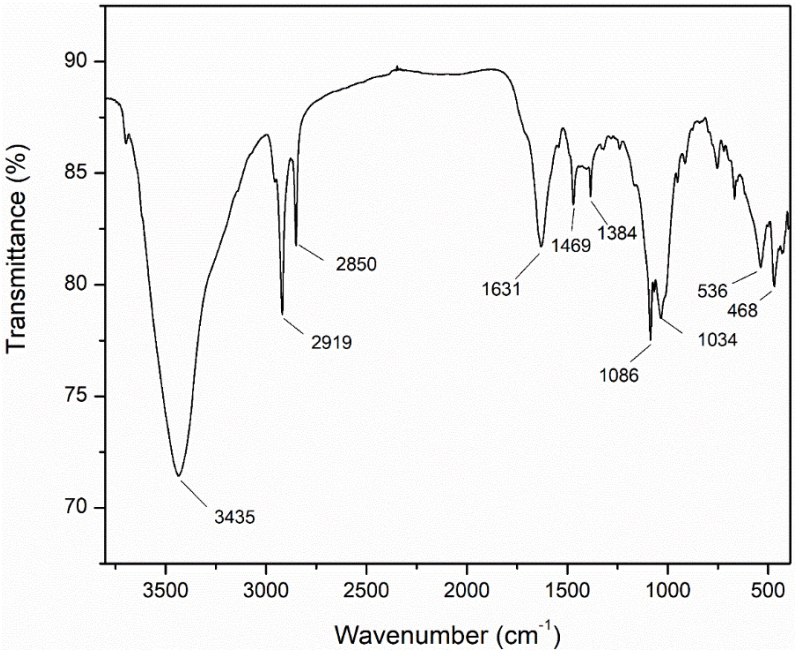


Figure S12. FT-IR spectrum of extracted nitro-lignin derivatives.

XPS Spectroscopy

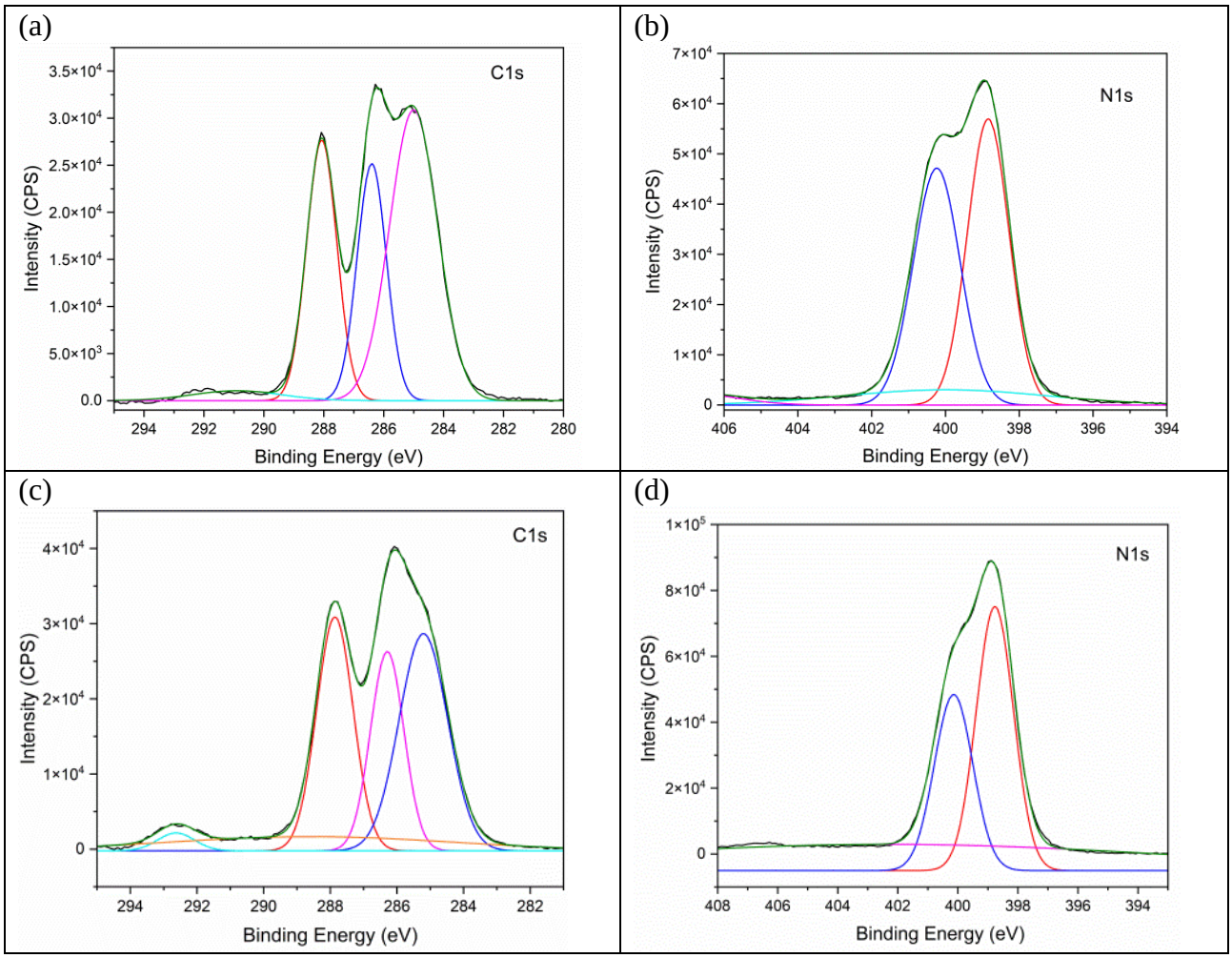


Figure S13. Deconvoluted C1s and N1s XPS spectra of **Mn-GU** (a, b) and **Cu-GU** (c, d).

DSC Thermograms

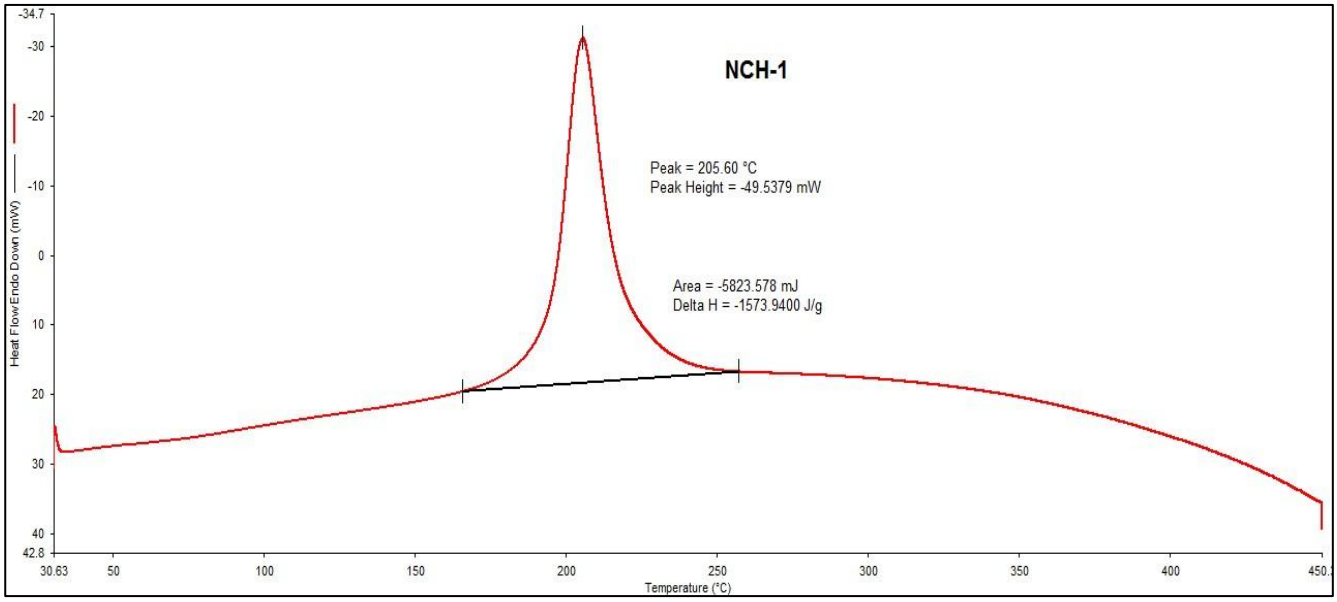


Figure S14. DSC thermogram of **NCH1.**

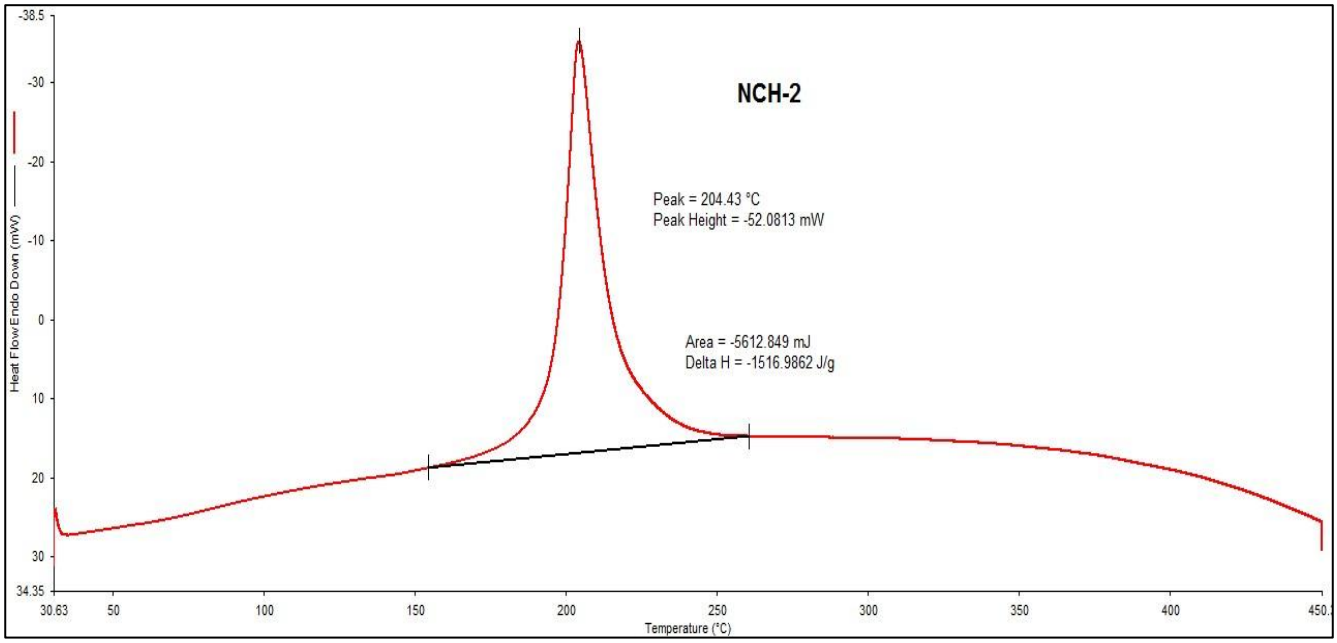


Figure S15. DSC thermogram of **NCH2.**

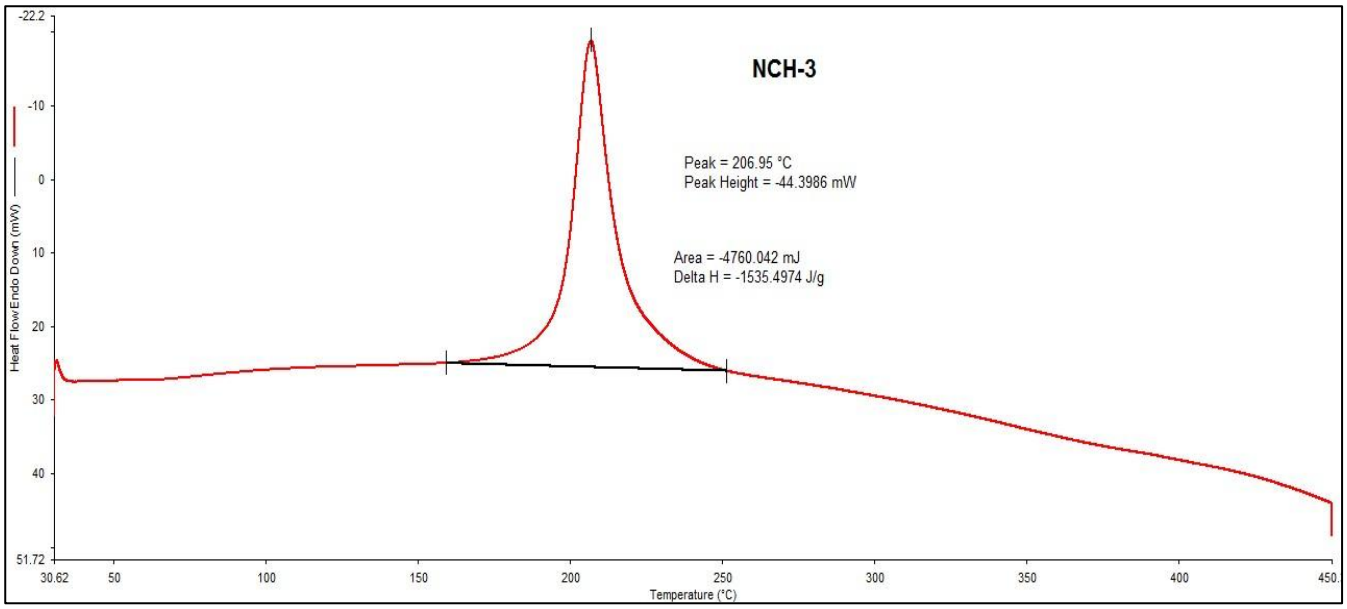


Figure S16. DSC thermogram of **NCH3.**

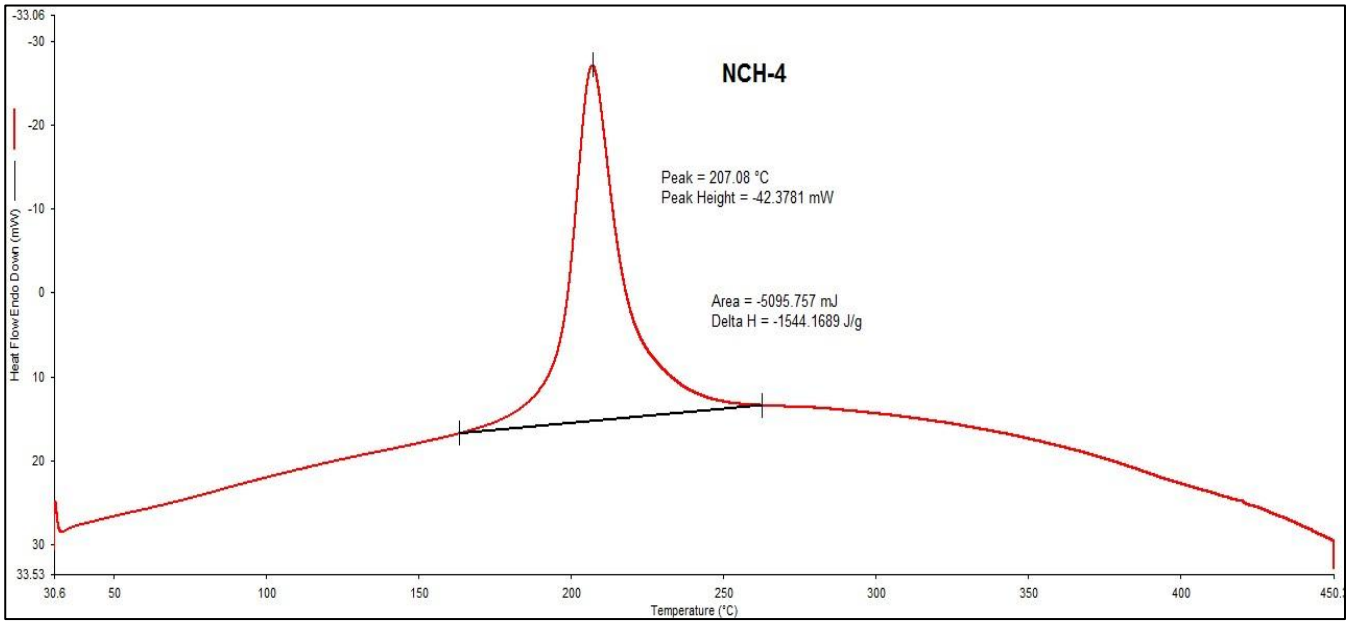


Figure S17. DSC thermogram of **NCH4.**

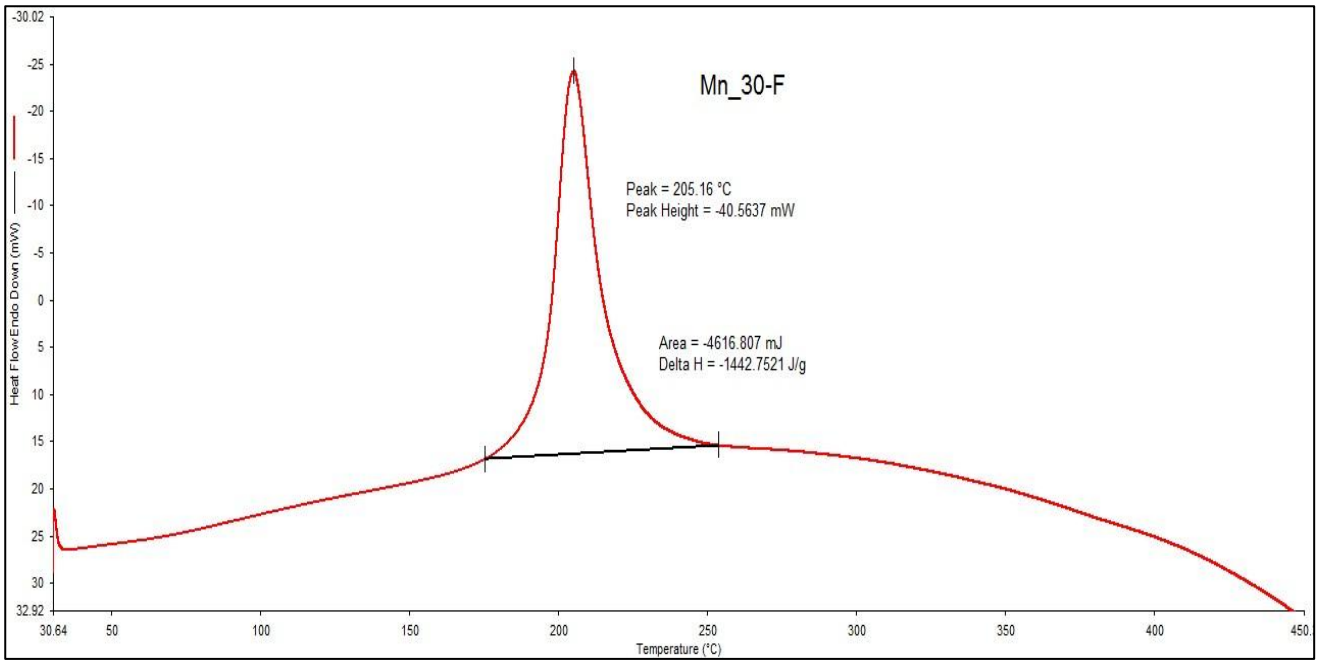


Figure S18. DSC thermogram of **F1** formulation.

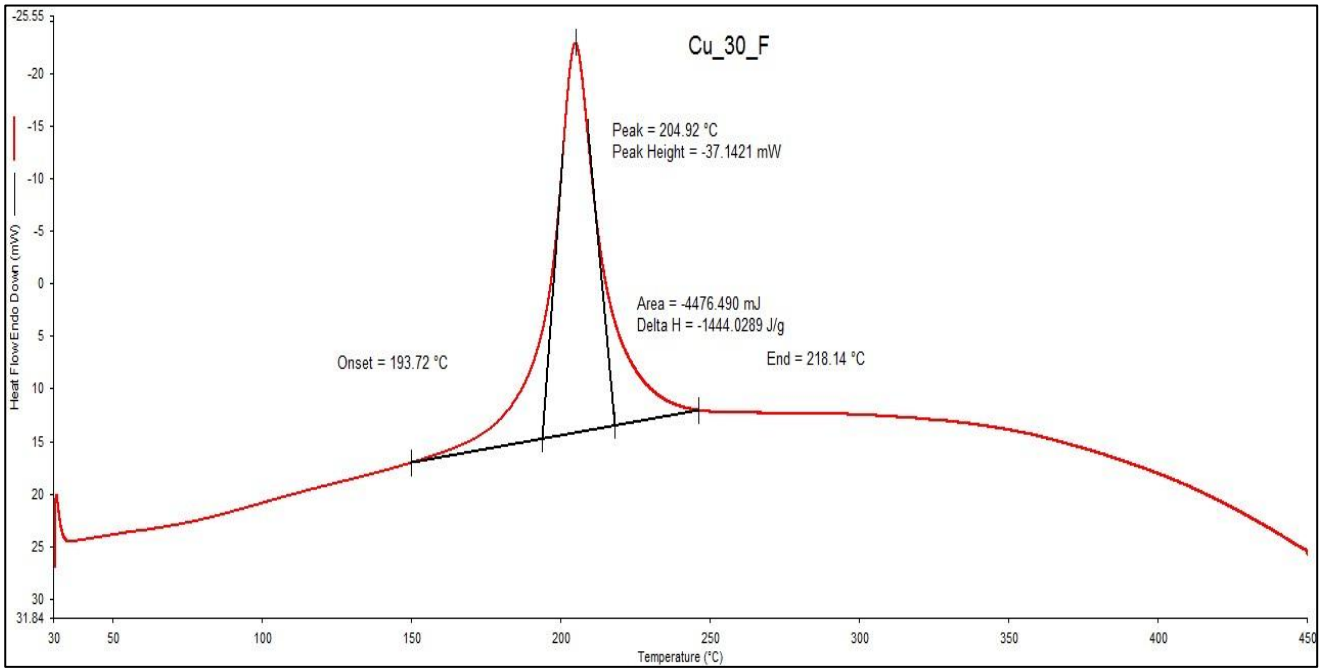
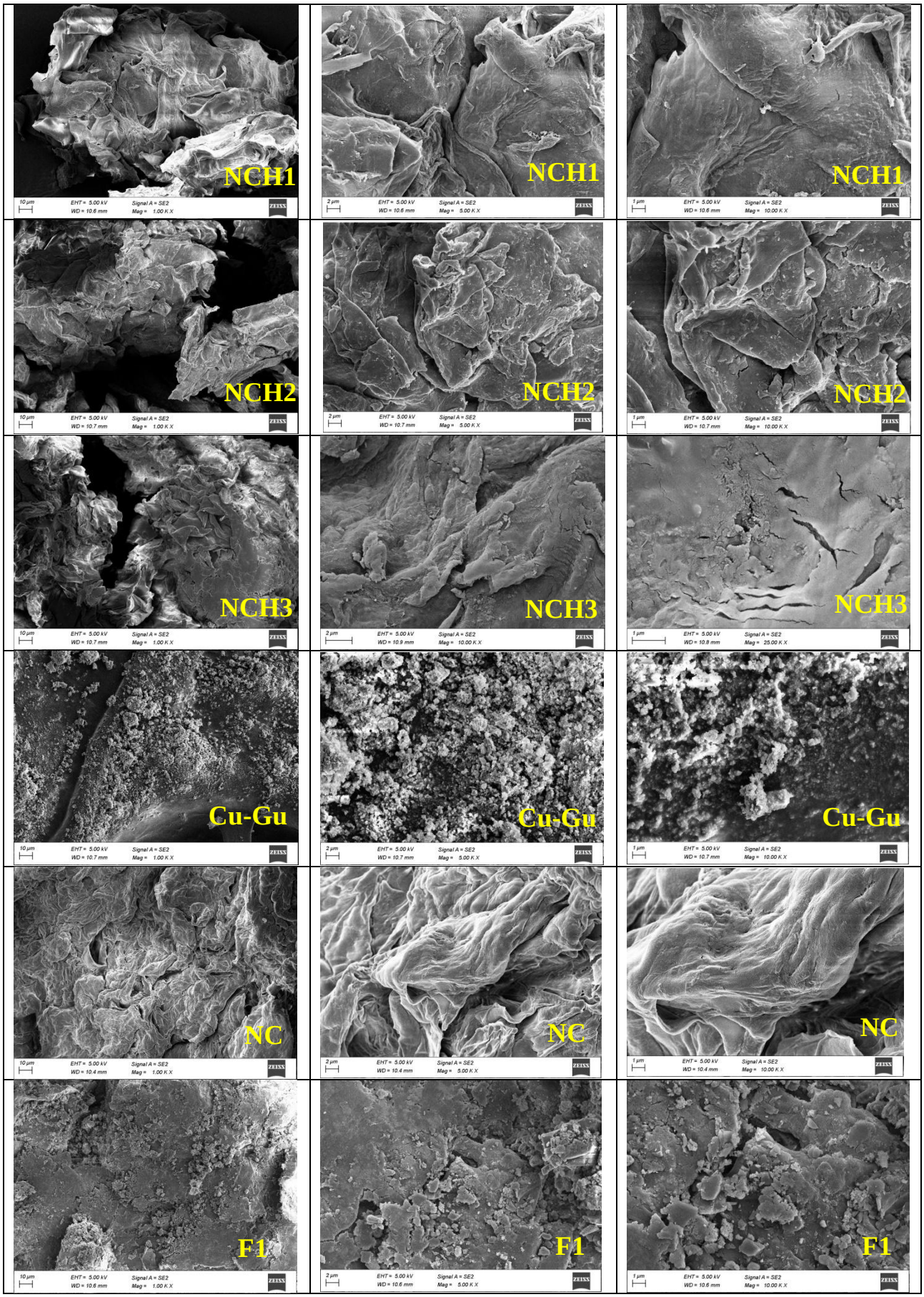


Figure S19. DSC thermogram of **F8** formulation.

SEM-EDS Analysis



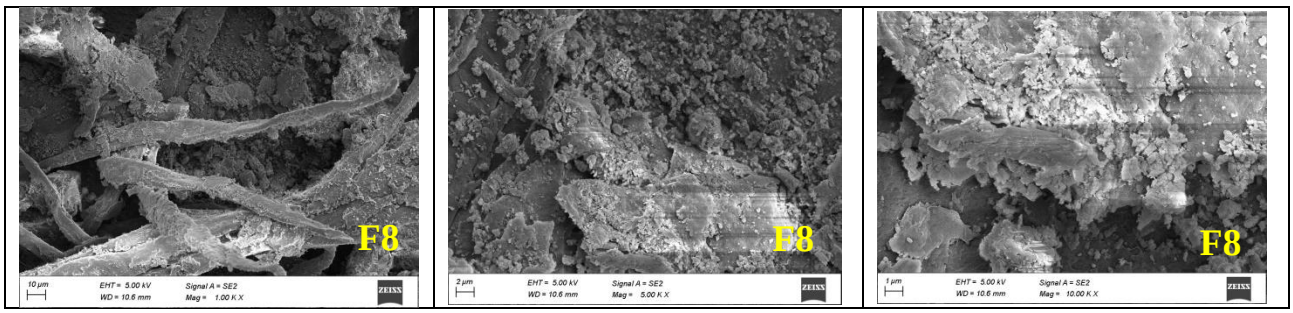


Figure S20. SEM images of **NCH1**, **NCH2**, **NCH3**, **Cu-GU**, **NC**, **F1**, and **F8** (from top to bottom).

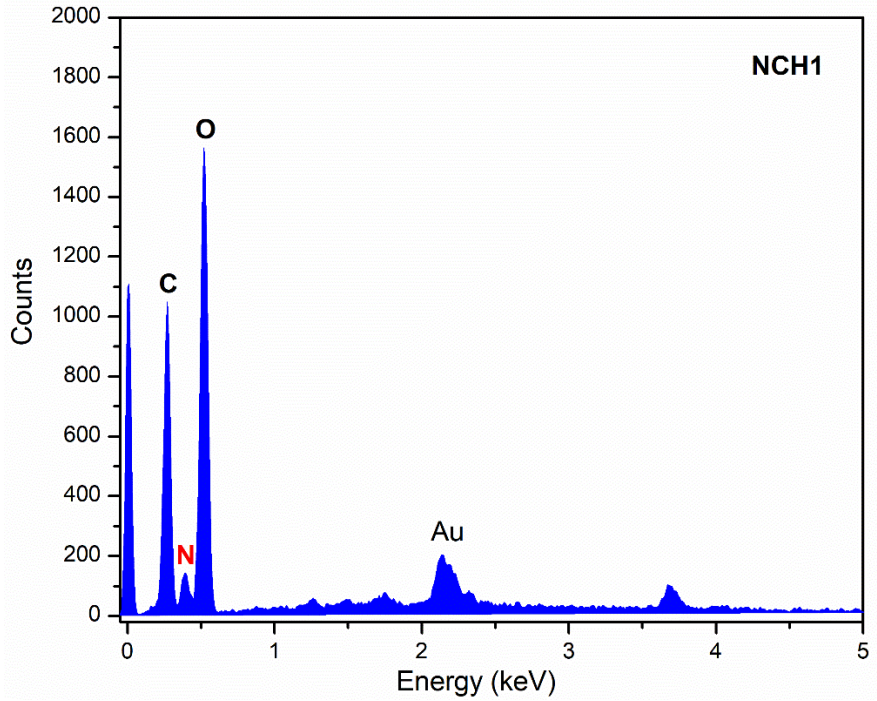


Figure S21. EDS spectrum of **NCH1.**

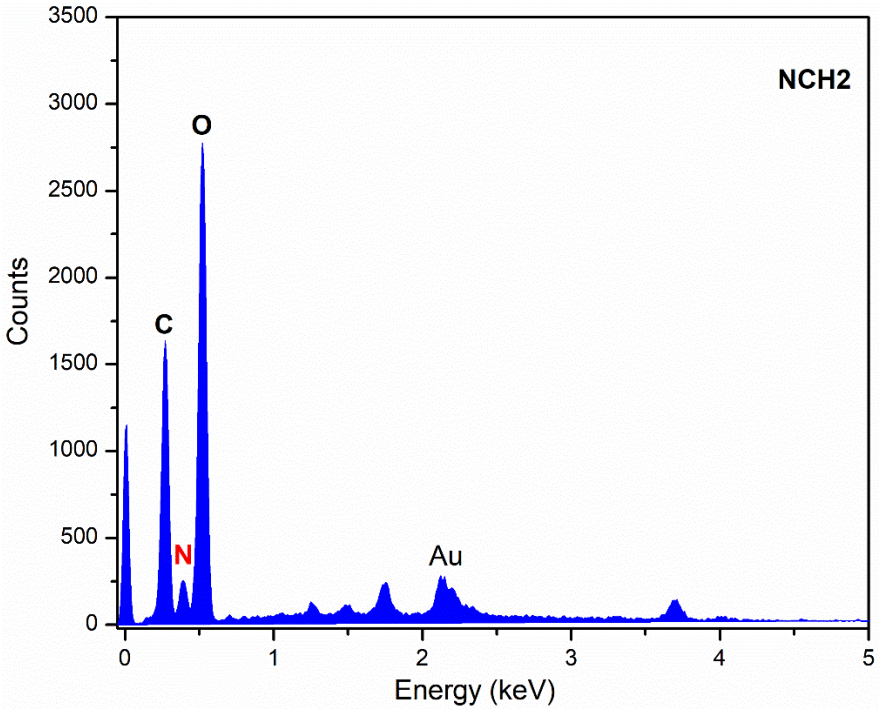


Figure S22. EDS spectrum of **NCH2.**

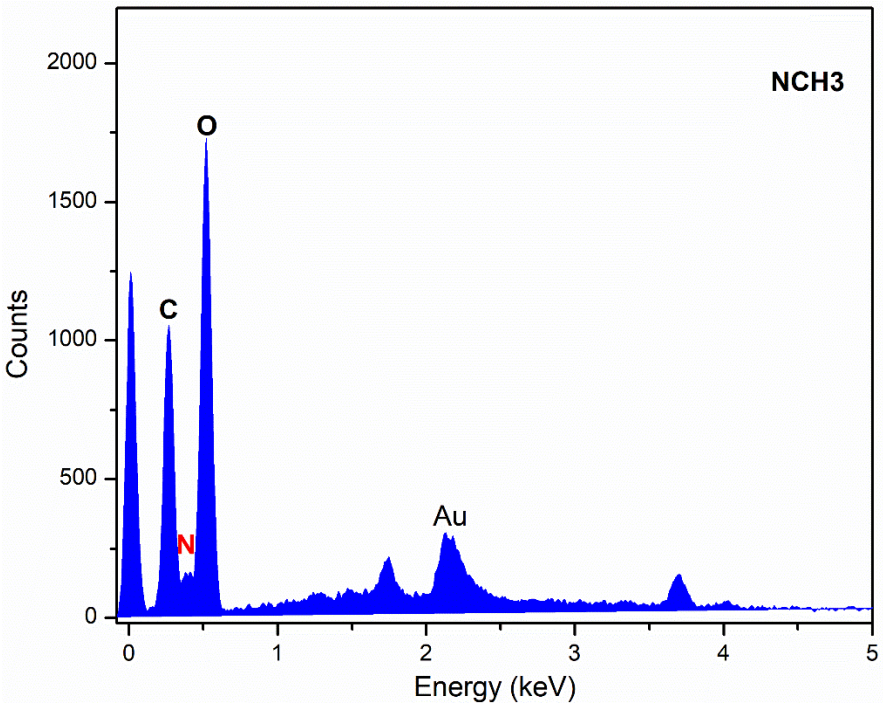


Figure S23. EDS spectrum of **NCH3.**

Table S1. Elemental composition of **NCH4** obtained from EDS.

Element	Weight%	Atomic%
C	27.11	32.50
N	14.91	15.32
O	57.98	52.18
Total	100.00	

Table S2. Elemental composition of **NCH3** obtained from EDS.

Element	Weight%	Atomic%
C	27.98	33.55
N	12.52	12.87
O	59.51	53.58
Total	100.00	

Table S3. Elemental composition of **NCH2** obtained from EDS.

Element	Weight%	Atomic%
C	27.14	32.65
N	11.86	12.24
O	61.00	55.11
Total	100.00	

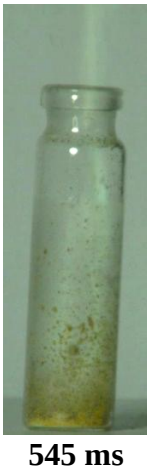
Table S4. Elemental composition of **NCH1** obtained from EDS.

Element	Weight%	Atomic%
C	28.50	34.16
N	11.83	12.16
O	59.67	53.68
Total	100.00	

Ignition Studies

Materials	Ignition				
Mn-Gu	 **-5 ms**	 **0 ms**	 **2 ms**	 **4 ms**	 **7 ms**
Cu-Gu	 **-5 ms**	 **0 ms**	 **2 ms**	 **10 ms**	 **23 ms**
NCH1 (75 wt.%) + **Mn-GU** (25 wt.%) (**F5**)	 **-5 ms**	 **0 ms**	 **43 ms**	 **53 ms**	 **70 ms**
NCH2 (75 wt.%) + **Mn-GU** (25 wt.%) (**F6**)	 **-5 ms**	 **0 ms**	 **51 ms**	 **53 ms**	 **58 ms**

NCH3 (75 wt.%) + **Mn-GU** (25 wt.%) **(F7)**	 **-5 ms**	 **0 ms**	 **44 ms**	 **48 ms**	 **56 ms**
NCH4 (70 wt.%) + **Cu-GU** (30 wt.%) **(F8)**	 **-5 ms**	 **0 ms**	 **159 ms**	 **164 ms**	 **174 ms**
NCH4 (75 wt.%) + **Cu-GU** (25 wt.%) **(F9)**	 **-5 ms**	 **0 ms**	 **158 ms**	 **161 ms**	 **165 ms**
NCH4 (75 wt.%) + **JN15** (25 wt.%) **(F10)**	 **-5 ms**	 **0 ms**	 **19 ms**	 **21 ms**	 **27 ms**

NCH4 (85 wt.%) + **JN15** (15 wt.%) (**F11**)	 **-5 ms**	 **0 ms**	 **38 ms**	 **40 ms**	 **45 ms**
NC-CH (75 wt.%) + **Mn-GU** (25 wt.%) (**F12**)	 **-5 ms**	 **0 ms**	 **40 ms**	 **41 ms**	 **42 ms**
NCH4 (75 wt.%) + **MnO_2** (25 wt.%) (**F17**)	 **-5 ms**	 **0 ms**	 **733 ms**	 **734 ms**	 **735 ms**
NCH4 (75 wt.%) + **$CuCl_2 \cdot 2H_2O$** (25 wt.%) (**F18**)	 **-5 ms**	 **0 ms**	 **510 ms**	 **513 ms**	 **545 ms**

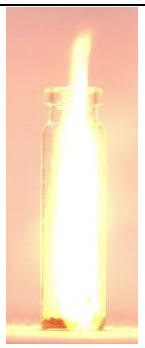
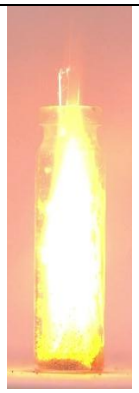
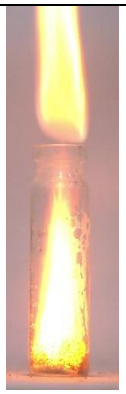
NC-CH (85 wt.%) + **JN15** (15 wt.%) (**F19**)	 **-10 ms**	 **0 ms**	 **26 ms**	 **29 ms**	 **41 ms**
NCH4 (85 wt.%) + **JN14** (15 wt.%) (**F20**)	 **-7 ms**	 **0 ms**	 **115 ms**	 **119 ms**	 **125 ms**
NCH4 (85 wt.%) + **[FcCH$_2$N(Me$_3$)][I]** (15 wt.%) (**F21**)	 **-10 ms**	 **0 ms**	 **278 ms**	 **281 ms**	 **291 ms**
NCH4 (90 wt.%) + **JN15** (10 wt.%) (**F22**)	 **-10 ms**	 **0 ms**	 **162 ms**	 **166 ms**	 **175 ms**

Figure S24. Ignition images of **NCH** formulations.

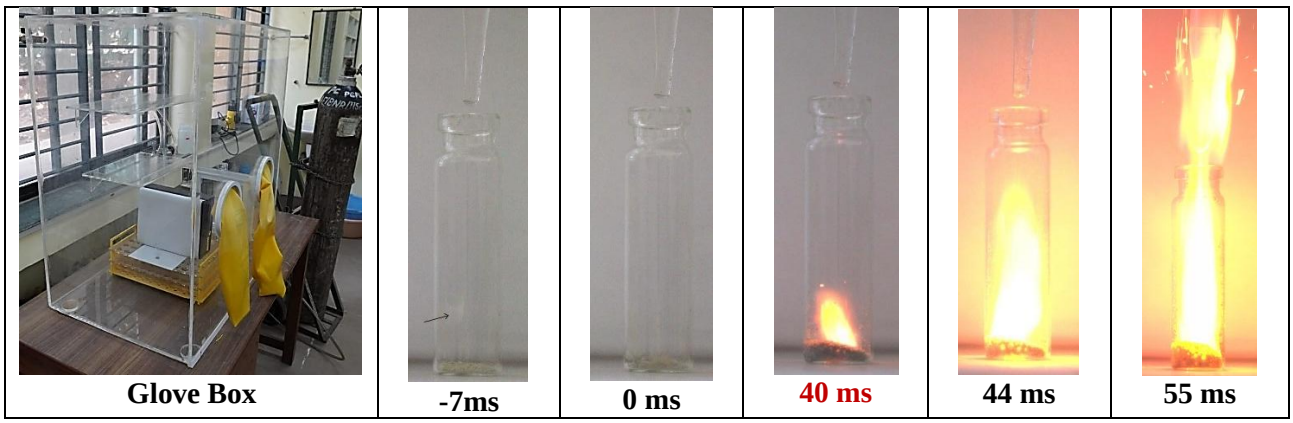


Figure S25. Image of Glove Box and ignition images of **F11** under N_2 atmosphere.

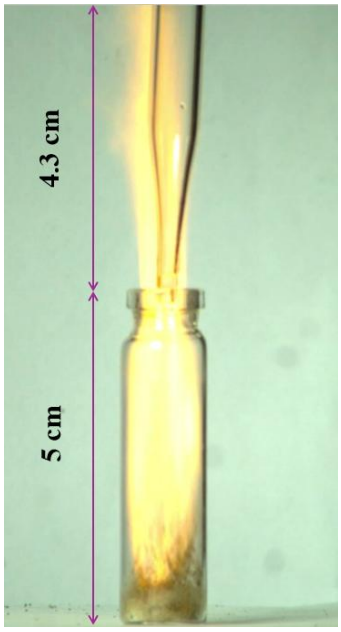


Figure S26. Measurement of flame height for formulation **F4**

Enthalpy of formation calculation

$\Delta H_{f,\ reactant} = \Delta H_{f,\ product} - \Delta H_c$

$= \Delta H_{f,\ product} - (\Delta U_c + \Delta n_g\ RT)$

Bomb calorimetry measurement was used to obtain the values ΔU_c.

For **NCH4**,

$$C_9H_{11}N_4O_{14}\ (s) + 4.75\ O_2\ (g) \longrightarrow 9\ CO_2\ (g) + 5.5\ H_2O\ (l) + 2\ N_2\ (g)$$

$\Delta H_c = \Delta U_c + \Delta n_g\ RT$

$= -3{,}449.09 + (9 + 2 - 4.75)\ (0.00831)\ (298.2)$

$= -3{,}449.09 + 15.49$

$=$ **$-3{,}433.6$ KJ·mol^{-1}**

$\Delta H_{f,} = (9 \times \Delta H_{f,\ CO2}) + (5.5 \times \Delta H_{f,\ H2O}) - \Delta H_c$

$= \{9 \times (-393.51)\} + \{5.5 \times (-285.83)\} - (-3{,}433.6)$

$= -3{,}541.59 - 1{,}572.07 + 3{,}433.6$

$=$ **-1680.06 KJ·mol^{-1}**

For **Mn-Gu**,

$$C_{10}H_{14}N_{10}MnO_5\ (s) + 12\ O_2\ (g) \longrightarrow 10\ CO_2\ (g) + 7\ H_2O\ (l) + 5\ N_2\ (g) + MnO_2\ (s)$$

$\Delta H_c = \Delta U_c + \Delta n_g\ RT$

$= -4{,}096.39 + (10 + 5 - 12)\ (0.00831)\ (298.2)$

$= -4{,}096.39 + 7.43$

$=$ **$-4{,}088.96$ KJ·mol^{-1}**

$\Delta H_{f,} = (10 \times \Delta H_{f,\ CO2}) + (7 \times \Delta H_{f,\ H2O}) + (1 \times \Delta H_{f,\ MnO2}) - \Delta H_c$

$= \{10 \times (-393.51)\} + \{7 \times (-285.83)\} + \{1 \times (-260.0)\} - (-4{,}088.96)$

$= -3{,}935.1 - 2000.81 - 260.0 + 4{,}088.96$

$=$ **$-2{,}106.95$ KJ·mol^{-1}**

For **Cu-Gu**,

$$C_{10}H_{14}N_{10}CuO_5\ (s) + 11.5\ O_2\ (g) \longrightarrow 10\ CO_2\ (g) + 7\ H_2O\ (l) + 5\ N_2\ (g) + CuO\ (s)$$

$\Delta H_c = \Delta U_c + \Delta n_g\ RT$

$= -3{,}902.5 + (10 + 5 - 11.5)\ (0.00831)\ (298.2)$

$= -3{,}902.5 + 8.67$

$=$ **$-3{,}893.83$ KJ·mol^{-1}**

$\Delta H_f = (10 \times \Delta H_{f,\ CO2}) + (6 \times \Delta H_{f,\ H2O}) + (2 \times \Delta H_{f,\ CuO}) - \Delta H_c$

$= \{10 \times (-393.51)\} + \{6 \times (-285.83)\} - \{2 \times (-155.2)\} - (-3{,}893.83)$

$= -3{,}935.1 - 1{,}714.98 - 310.4 + 3{,}893.83$

$=$ **$-2{,}066.65$ KJ·mol^{-1}**

Specific Impulse Calculation

*Calculation for **Mn-Gu** with H_2O_2 (95%)*

Combustion condition:

Isobaric combustion (p=const.)
Chamber pressure = 7.000 MPa
Ambient pressure = 0.100 MPa
Expansion conditions: Equilibrium expansion

Reactant information:

1. Mn-Gu, 33.33 %
2. Water (H2O, liquid), 3.33 %
3. Hydrogen peroxide (H2O2), 63.34 %

C(0.383) H(2.459) N(0.383) O(2.028) Mn(0.038)

Molecular weight = 46.98
Oxygen balance = -0.1774111 %
Enthalpy of formation = -5738.36 kJ/kg
Internal energy of formation = -5609.90 kJ/kg

Parameters in combustion chamber:

- Heat of isobaric combustion = -3908.40 kJ/kg
- Total enthalpy of combustion prod. = -5738.43 kJ/kg
- Entropy of combustion products = 10.03 kJ/K kg
- Isobaric combustion temperature = 2465.7 K
- Mole number of gaseous products = 38.691 mol/kg expl.
- Total mole number of products = 39.505 mol/kg expl.
- Volume of gaseous products (at SATP) = 959.11 L/kg expl.
- Mass of gaseous products = 942.2 g/kg expl.
- Mass of condensed products = 57.8 g/kg expl.
- Mean molecular mass of gaseous prod. = 24.353 g
- Mean molecular mass of all products = 25.313 g
- Specific gas constant = 321.677 J/kg K
- Specific heat capacity at p=const. (Cp) = 2097.63 J/kgK
- Specific heat capacity at V=const. (Cv) = 1775.95 J/molK
- Specific heat ratio (Cp/Cv) = 1.1811

Composition of combustion products in chamber:

Products	mol/mol	mol/kg	Mol %
H2O =	1.215568 E00	2.587296 E01	65.4922
CO2 =	3.635774 E-01	7.738622 E00	19.5888
N2 =	1.901423 E-01	4.047115 E00	10.2445
MnO(s) =	3.826522 E-02	8.144625 E-01	2.0616
CO =	1.907484 E-02	4.060015 E-01	1.0277
H2 =	9.784988 E-03	2.082702 E-01	0.5272
O2 =	8.611356 E-03	1.832898 E-01	0.4640
OH =	8.114763 E-03	1.727200 E-01	0.4372
NO =	2.367373 E-03	5.038873 E-02	0.1275
H =	3.606505 E-04	7.676325 E-03	0.0194
O =	1.832387 E-04	3.900174 E-03	0.0099
NH3 =	2.097813 E-07	4.465125 E-06	0.0000
NH2 =	2.180352 E-08	4.640807 E-07	0.0000
N =	1.093597 E-08	2.327685 E-07	0.0000

CHNO =	9.361409 E-09	1.992545 E-07	0.0000
HCN =	4.807718 E-10	1.023307 E-08	0.0000
CNO =	1.208458 E-10	2.572161 E-09	0.0000
MnO2(s) =	1.626566 E-13	3.462092 E-12	0.0000
CH4 =	9.125147 E-14	1.942257 E-12	0.0000
CH3OH =	8.365720 E-14	1.780615 E-12	0.0000

Parameters at the nozzle throat:

- Total enthalpy of combustion prod. = -6173.15 kJ/kg
- Temperature at nozzle throat = 2292.4 K
- Pressure at nozzle throat = 4.0 MPa
- Mole number of gaseous products = 38.561 mol/kg expl.
- Total mole number of products = 39.376 mol/kg expl.
- Volume of gaseous products (at SATP) = 955.90 L/kg expl.
- Mass of gaseous products = 942.2 g/kg expl.
- Mass of condensed products = 57.8 g/kg expl.
- Mean molecular mass of gaseous prod. = 24.435 g
- Mean molecular mass of all products = 25.397 g
- Specific gas constant = 320.599 J/kg K
- Specific heat capacity at p=const. (Cp) = 2067.65 J/kgK
- Specific heat capacity at V=const. (Cv) = 1747.05 J/molK
- Specific heat ratio (Cp/Cv) = 1.1835

Characteristic parameters at the nozzle throat:

- Flow velocity at nozzle throat = 932.4 m/s
- Sound velocity at throat) = 932.6 m/s
- Mach number at nozzle throat = 1.000
- Critical pressure ratio (pt/pc) = 0.566
- Pressure ratio (pc/pt) = 1.767

Composition of combustion products at nozzle throat:

Products	mol/mol	mol/kg	Mol %
H2O =	1.220530 E00	2.597857 E01	65.9759
CO2 =	3.704908 E-01	7.885772 E00	20.0269
N2 =	1.906807 E-01	4.058574 E00	10.3073
MnO(s) =	3.826522 E-02	8.144625 E-01	2.0684
CO =	1.216143 E-02	2.588521 E-01	0.6574
H2 =	6.723247 E-03	1.431020 E-01	0.3634
O2 =	5.072265 E-03	1.079615 E-01	0.2742
OH =	4.505346 E-03	9.589477 E-02	0.2435
NO =	1.290836 E-03	2.747500 E-02	0.0698
H =	1.709608 E-04	3.638844 E-03	0.0092
O =	7.245873 E-05	1.542260 E-03	0.0039
NH3 =	8.309504 E-08	1.768650 E-06	0.0000
NH2 =	5.750818 E-09	1.224042 E-07	0.0000
CHNO =	2.672251 E-09	5.687796 E-08	0.0000
N =	2.465715 E-09	5.248191 E-08	0.0000
HCN =	1.056629 E-10	2.249000 E-09	0.0000
CNO =	2.062105 E-11	4.389121 E-10	0.0000
MnO2(s) =	1.477906 E-13	3.145673 E-12	0.0000
CH4 =	1.407809 E-14	2.996475 E-13	0.0000
CH3OH =	1.158812 E-14	2.466493 E-13	0.0000

Parameters at the nozzle exit:

- Total enthalpy of combustion prod. = -8244.70 kJ/kg
- Temperature at nozzle exit = 1280.9 K
- Pressure at nozzle throat = 0.1 MPa
- Mole number of gaseous products = 38.388 mol/kg expl.
- Total mole number of products = 39.203 mol/kg expl.
- Volume of gaseous products (at SATP) = 951.61 L/kg expl.
- Mass of gaseous products = 942.2 g/kg expl.
- Mass of condensed products = 57.8 g/kg expl.
- Mean molecular mass of gaseous prod. = 24.545 g
- Mean molecular mass of all products = 25.509 g
- Specific gas constant = 319.161 J/kg K
- Specific heat capacity at p=const. (Cp) = 1806.81 J/kgK
- Specific heat capacity at V=const. (Cv) = 1487.65 J/molK
- Specific heat ratio (Cp/Cv) = 1.2145

Characteristic parameters at the nozzle exit:

- Specific impulse = 228.22 s
- Exhaust (or nozzle exit) velocity = 2238.9 m/s
- Characteristic exhaust velocity (c*) = 1362.0 m/s
- Thrust coefficient (Cf) = 1.644
- Nozzle area expansion ratio (Ae/At) = 8.81
- Pressure ratio (pc/pe) = 70.000
- Sound velocity at nozzle exit = 695.57 m/s
- Mach number at nozzle exit = 3.219

Composition of combustion products at the nozzle exit:

Products	mol/mol	mol/kg	Mol %
H2O =	1.226251 E00	2.610034 E01	66.5777
CO2 =	3.807826 E-01	8.104830 E00	20.6741
N2 =	1.913261 E-01	4.072312 E00	10.3878
MnO(s) =	3.826524 E-02	8.144627 E-01	2.0776
H2 =	3.340302 E-03	7.109720 E-02	0.1814
CO =	1.869685 E-03	3.979561 E-02	0.1015
OH =	2.104615 E-07	4.479601 E-06	0.0000
H =	7.364316 E-08	1.567470 E-06	0.0000
NH3 =	1.103877 E-08	2.349565 E-07	0.0000
NO =	8.478148 E-09	1.804545 E-07	0.0000
CNO =	1.777050 E-09	3.782392 E-08	0.0000
N =	1.609303 E-09	3.425349 E-08	0.0000
CH3OH =	1.598442 E-09	3.402230 E-08	0.0000
CH4 =	1.102867 E-09	2.347415 E-08	0.0000
MnO2(s) =	1.024600 E-09	2.180826 E-08	0.0000
NH2 =	7.143529 E-10	1.520476 E-08	0.0000
HCN =	7.072556 E-10	1.505370 E-08	0.0000
O =	4.629781 E-10	9.854332 E-09	0.0000
CHNO =	3.920790 E-10	8.345269 E-09	0.0000
O2 =	2.293251 E-10	4.881108 E-09	0.0000

*Calculation for **Cu-Gu** with H_2O_2 (95%)*

Combustion condition:

Isobaric combustion (p=const.)
Chamber pressure = 7.000 MPa
Ambient pressure = 0.100 MPa
Expansion conditions: Equilibrium expansion

Reactant information:

1. Cu-Gu, 33.33%
2. Hydrogen peroxide (H2O2), 63.33%
3. Water (H2O, liquid), 3.34%

C(0.375) H(2.450) N(0.375) O(2.025) Cu(0.038)

Molecular weight = 47.01
Oxygen balance = 0.4354499%
Enthalpy of formation = -5671.89 kJ/kg
Internal energy of formation = -5544.03 kJ/kg

Parameters in combustion chamber:

- Heat of isobaric combustion = -3725.70 kJ/kg
- Total enthalpy of combustion prod. = -5671.96 kJ/kg
- Entropy of combustion products = 9.90 kJ/K kg
- Isobaric combustion temperature = 2390.4 K
- Mole number of gaseous products = 38.545 mol/kg expl.
- Total mole number of products = 38.941 mol/kg expl.
- Volume of gaseous products (at SATP) = 955.50 L/kg expl.
- Mass of gaseous products = 943.3 g/kg expl.
- Mass of condensed products = 56.7 g/kg expl.
- Mean molecular mass of gaseous prod. = 24.474 g
- Mean molecular mass of all products = 25.680 g
- Specific gas constant = 320.467 J/kg K
- Specific heat capacity at p=const. (Cp) = 2079.29 J/kgK
- Specific heat capacity at V=const. (Cv) = 1758.82 J/molK
- Specific heat ratio (Cp/Cv) = 1.1822

Composition of combustion products in chamber:

Products	mol/mol	mol/kg	Mol %
H2O =	1.216589 E00	2.587745 E01	66.4522
CO2 =	3.665011 E-01	7.795660 E00	20.0189
N2 =	1.860123 E-01	3.956574 E00	10.1603
O2 =	1.875113 E-02	3.988459 E-01	1.0242
Cu2O(s) =	1.861596 E-02	3.959707 E-01	1.0168
CO =	8.515811 E-03	1.811355 E-01	0.4651
OH =	7.672553 E-03	1.631990 E-01	0.4191
H2 =	4.498717 E-03	9.568993 E-02	0.2457
NO =	2.992134 E-03	6.364417 E-02	0.1634
CuO =	2.697619 E-04	5.737969 E-03	0.0147
O =	1.818574 E-04	3.868197 E-03	0.0099
H =	1.721098 E-04	3.660860 E-03	0.0094
NH3 =	7.096425 E-08	1.509445 E-06	0.0000

NH2 =	7.523928 E-09	1.600377 E-07	0.0000
N =	5.157235 E-09	1.096969 E-07	0.0000
CHNO =	2.761966 E-09	5.874838 E-08	0.0000
HCN =	7.131669 E-11	1.516941 E-09	0.0000
CNO =	3.470778 E-11	7.382516 E-10	0.0000
CuO(s) =	1.166396 E-11	2.480982 E-10	0.0000
Cu(OH)2(s) =	6.817410 E-14	1.450097 E-12	0.0000
CH3OH =	9.351569 E-15	1.989125 E-13	0.0000

Parameters at the nozzle throat:

- Total enthalpy of combustion prod. = -6091.34 kJ/kg
- Temperature at nozzle throat = 2213.4 K
- Pressure at nozzle throat = 4.0 MPa
- Mole number of gaseous products = 38.451 mol/kg expl.
- Total mole number of products = 38.849 mol/kg expl.
- Volume of gaseous products (at SATP) = 953.17 L/kg expl.
- Mass of gaseous products = 943.1 g/kg expl.
- Mass of condensed products = 56.9 g/kg expl.
- Mean molecular mass of gaseous prod. = 24.527 g
- Mean molecular mass of all products = 25.741 g
- Specific gas constant = 319.685 J/kg K
- Specific heat capacity at p=const. (Cp) = 2045.47 J/kgK
- Specific heat capacity at V=const. (Cv) = 1725.78 J/molK
- Specific heat ratio (Cp/Cv) = 1.1852

Characteristic parameters at the nozzle throat:

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- Flow velocity at nozzle throat = 915.8 m/s
- Sound velocity at throat) = 915.8 m/s
- Mach number at nozzle throat = 1.000
- Critical pressure ratio (pt/pc) = 0.566
- Pressure ratio (pc/pt) = 1.767

Composition of combustion products at nozzle throat:

Products	mol/mol	mol/kg	Mol %
H2O =	1.220434 E00	2.595924 E01	66.8205
CO2 =	3.710349 E-01	7.892096 E00	20.3147
N2 =	1.865325 E-01	3.967638 E00	10.2129
Cu2O(s) =	1.870316 E-02	3.978254 E-01	1.0240
O2 =	1.677208 E-02	3.567504 E-01	0.9183
OH =	4.479400 E-03	9.527905 E-02	0.2453
CO =	3.982016 E-03	8.469944 E-02	0.2180
H2 =	2.303577 E-03	4.899822 E-02	0.1261
NO =	1.951905 E-03	4.151798 E-02	0.1069
CuO =	9.537531 E-05	2.028680 E-03	0.0052
O =	8.151632 E-05	1.733892 E-03	0.0045
H =	6.525089 E-05	1.387919 E-03	0.0036
NH3 =	1.827980 E-08	3.888203 E-07	0.0000
NH2 =	1.382457 E-09	2.940555 E-08	0.0000
N =	9.903057 E-10	2.106429 E-08	0.0000
CHNO =	4.950256 E-10	1.052944 E-08	0.0000
CuO(s) =	1.303860 E-11	2.773375 E-10	0.0000

HCN =	6.882688 E-12	1.463982 E-10	0.0000
CNO =	3.954276 E-12	8.410941 E-11	0.0000
Cu(OH)2(s) =	4.639555 E-14	9.868562 E-13	0.0000
CH3OH =	5.335786 E-16	1.134948 E-14	0.0000

Parameters at the nozzle exit:

- Total enthalpy of combustion prod. = -8067.65 kJ/kg
- Temperature at nozzle exit = 1213.8 K
- Pressure at nozzle throat = 0.1 MPa
- Mole number of gaseous products = 38.357 mol/kg expl.
- Total mole number of products = 38.756 mol/kg expl.
- Volume of gaseous products (at SATP) = 950.84 L/kg expl.
- Mass of gaseous products = 942.9 g/kg expl.
- Mass of condensed products = 57.1 g/kg expl.
- Mean molecular mass of gaseous prod. = 24.583 g
- Mean molecular mass of all products = 25.803 g
- Specific gas constant = 318.902 J/kg K
- Specific heat capacity at p=const. (Cp) = 1770.01 J/kgK
- Specific heat capacity at V=const. (Cv) = 1451.11 J/molK
- Specific heat ratio (Cp/Cv) = 1.2198

Characteristic parameters at the nozzle exit:

- Specific impulse = 223.13 s
- Exhaust (or nozzle exit) velocity = 2188.9 m/s
- Characteristic exhaust velocity (c*) = 1338.4 m/s
- Thrust coefficient (Cf) = 1.635
- Nozzle area expansion ratio (Ae/At) = 8.72
- Pressure ratio (pc/pe) = 70.000
- Sound velocity at nozzle exit = 677.35 m/s
- Mach number at nozzle exit = 3.232

Composition of combustion products at the nozzle exit:

Products	mol/mol	mol/kg	Mol %
H2O =	1.225007 E00	2.605650 E01	67.2318
CO2 =	3.750168 E-01	7.976794 E00	20.5820
N2 =	1.874981 E-01	3.988178 E00	10.2904
Cu2O(s) =	1.874595 E-02	3.987356 E-01	1.0288
O2 =	1.575908 E-02	3.352034 E-01	0.8649
NO =	2.062536 E-05	4.387115 E-04	0.0011
CuO(s) =	9.793260 E-06	2.083075 E-04	0.0005
OH =	6.577488 E-06	1.399064 E-04	0.0004
H2 =	1.861422 E-07	3.959337 E-06	0.0000
CO =	6.687105 E-08	1.422380 E-06	0.0000
Cu(OH)2(s) =	3.654384 E-10	7.773055 E-09	0.0000
O =	3.630495 E-10	7.722242 E-09	0.0000
H =	1.441310 E-10	3.065739 E-09	0.0000
CuO =	4.526008 E-11	9.627044 E-10	0.0000
CH3OH =	4.115097 E-11	8.753014 E-10	0.0000
HCN =	2.775455 E-11	5.903531 E-10	0.0000
CNO =	2.482053 E-11	5.279450 E-10	0.0000
CHNO =	1.461540 E-11	3.108768 E-10	0.0000

N =	1.397480 E-11	2.972510 E-10	0.0000
NH2 =	1.355363 E-11	2.882924 E-10	0.0000
NH3 =	6.783649 E-12	1.442916 E-10	0.0000

*Calculation for **F1** with H_2O_2 (95%)*

Combustion condition:

Isobaric combustion (p=const.)
Chamber pressure = 7.000 MPa
Ambient pressure = 0.100 MPa
Expansion conditions: Equilibrium expansion

Reactant information:

1. Water (H_2O, liquid), 2.78 %
2. Hydrogen peroxide (H_2O_2), 52.78%
3. **Mn-Gu**, 13.33%
4. NCH4, 31.11%

C(0.565) H(2.601) N(0.351) O(2.484) Mn(0.018)

Molecular weight = 55.05
Oxygen balance = 0.9946645%
Enthalpy of formation = -5348.16 kJ/kg
Internal energy of formation = -5225.78 kJ/kg

Parameters in combustion chamber:

- Heat of isobaric combustion = -4196.83 kJ/kg
- Total enthalpy of combustion prod. = -5348.13 kJ/kg
- Entropy of combustion products = 10.04 kJ/K kg
- Isobaric combustion temperature = 2651.2 K
- Mole number of gaseous products = 37.980 mol/kg expl.
- Total mole number of products = 38.306 mol/kg expl.
- Volume of gaseous products (at SATP) = 941.50 L/kg expl.
- Mass of gaseous products = 976.9 g/kg expl.
- Mass of condensed products = 23.1 g/kg expl.
- Mean molecular mass of gaseous prod. = 25.721 g
- Mean molecular mass of all products = 26.106 g
- Specific gas constant = 315.769 J/kg K
- Specific heat capacity at p = const. (Cp) = 2065.79 J/kgK
- Specific heat capacity at V = const. (Cv) = 1750.02 J/molK
- Specific heat ratio (Cp/Cv) = 1.1804

Composition of combustion products in chamber:

Products	**mol/mol**	**mol/kg**	**Mol %**
H_2O =	1.276465 E00	2.318744 E01	60.5319
CO_2 =	5.271857 E-01	9.576513 E00	24.9999
N_2 =	1.723844 E-01	3.131423 E00	8.1747
CO =	3.824285 E-02	6.946948 E-01	1.8135
O2 =	3.421656 E-02	6.215559 E-01	1.6226
OH =	2.112406 E-02	3.837260 E-01	1.0017
MnO(s) =	1.793172 E-02	3.257361 E-01	0.8503
H_2 =	1.312924 E-02	2.384972 E-01	0.6226
NO =	6.153158 E-03	1.117743 E-01	0.2918

H =	9.777206 E-04	1.776064 E-02	0.0464
O =	9.377802 E-04	1.703511 E-02	0.0445
NH_3 =	2.261401 E-07	4.107914 E-06	0.0000
N =	5.776586 E-08	1.049337 E-06	0.0000
NH2 =	4.883098 E-08	8.870319 E-07	0.0000
CHNO =	1.897210 E-08	3.446348 E-07	0.0000
HCN =	1.266935 E-09	2.301432 E-08	0.0000
CNO =	5.634807 E-10	1.023582 E-08	0.0000
MnO2(s) =	1.971114 E-13	3.580598 E-12	0.0000
CH3OH =	1.697002 E-13	3.082664 E-12	0.0000
CH4 =	1.518725 E-13	2.758818 E-12	0.0000

Parameters at the nozzle throat:

- Total enthalpy of combustion prod. = -5808.96 kJ/kg
- Temperature at nozzle throat = 2483.4 K
- Pressure at nozzle throat = 4.0 MPa
- Mole number of gaseous products = 37.777 mol/kg expl.
- Total mole number of products = 38.103 mol/kg expl.
- Volume of gaseous products (at SATP) = 936.45 L/kg expl.
- Mass of gaseous products = 976.9 g/kg expl.
- Mass of condensed products = 23.1 g/kg expl.
- Mean molecular mass of gaseous prod. = 25.860 g
- Mean molecular mass of all products = 26.245 g
- Specific gas constant = 314.078 J/kg K
- Specific heat capacity at p=const. (Cp) = 2042.40 J/kgK
- Specific heat capacity at V=const. (Cv) = 1728.32 J/molK
- Specific heat ratio (Cp/Cv) = 1.1817

Characteristic parameters at the nozzle throat:

- Flow velocity at nozzle throat = 960.0 m/s
- Sound velocity at throat = 960.1 m/s
- Mach number at nozzle throat = 1.000
- Critical pressure ratio (pt/pc) = 0.566
- Pressure ratio (pc/pt) = 1.768

Composition of combustion products at nozzle throat:

Products	mol/mol	mol/kg	Mol %
H2O =	1.284402 E00	2.333161 E01	61.2335
CO2 =	5.407766 E-01	9.823398 E00	25.7814
N2 =	1.733550 E-01	3.149055 E00	8.2646
O2 =	2.812927 E-02	5.109780 E-01	1.3411
CO =	2.465195 E-02	4.478114 E-01	1.1753
MnO(s) =	1.793172 E-02	3.257361 E-01	0.8549
OH =	1.413617 E-02	2.567885 E-01	0.6739
H2 =	8.910898 E-03	1.618696 E-01	0.4248
NO =	4.212015 E-03	7.651273 E-02	0.2008
H =	5.297822 E-04	9.623680 E-03	0.0253
O =	5.139860 E-04	9.336736 E-03	0.0245
NH3 =	8.477874 E-08	1.540036 E-06	0.0000
N =	1.755272 E-08	3.188513 E-07	0.0000
NH2 =	1.424515 E-08	2.587681 E-07	0.0000
CHNO =	5.481529 E-09	9.957390 E-08	0.0000
HCN =	2.578581 E-10	4.684083 E-09	0.0000
CNO =	1.156275 E-10	2.100415 E-09	0.0000
MnO2(s) =	1.987496 E-13	3.610356 E-12	0.0000

CH3OH =	2.154639 E-14	3.913977 E-13	0.0000
CH4 =	1.944563 E-14	3.532368 E-13	0.0000

Parameters at the nozzle exit:

- Total enthalpy of combustion prod. = -8045.79 kJ/kg
- Temperature at nozzle exit = 1443.8 K
- Pressure at nozzle throat = 0.1 MPa
- Mole number of gaseous products = 37.397 mol/kg expl.
- Total mole number of products = 37.722 mol/kg expl.
- Volume of gaseous products (at SATP) = 927.03 L/kg expl.
- Mass of gaseous products = 976.9 g/kg expl.
- Mass of condensed products = 23.1 g/kg expl.
- Mean molecular mass of gaseous prod. = 26.123 g
- Mean molecular mass of all products = 26.510 g
- Specific gas constant = 310.916 J/kg K
- Specific heat capacity at p=const. (Cp) = 1814.37 J/kgK
- Specific heat capacity at V=const. (Cv) = 1503.46 J/molK
- Specific heat ratio (Cp/Cv) = 1.2068

Characteristic parameters at the nozzle exit:

- Specific impulse = 236.78 s
- Exhaust (or nozzle exit) velocity = 2322.8 m/s
- Characteristic exhaust velocity (c*) = 1397.1 m/s
- Thrust coefficient (Cf) = 1.663
- Nozzle area expansion ratio (Ae/At) = 8.94
- Pressure ratio (pc/pe) = 70.000
- Sound velocity at nozzle exit = 728.34 m/s
- Mach number at nozzle exit = 3.189

Composition of combustion products at the nozzle exit:

Products	mol/mol	mol/kg	Mol %
H2O =	1.300584 E00	2.362557 E01	62.6300
CO2 =	5.654184 E-01	1.027102 E01	27.2279
N2 =	1.754164 E-01	3.186501 E00	8.4472
MnO(s) =	1.793178 E-02	3.257371 E-01	0.8635
O2 =	1.705126 E-02	3.097421 E-01	0.8211
OH =	1.041603 E-04	1.892109 E-03	0.0050
NO =	8.944602 E-05	1.624819 E-03	0.0043
CO =	1.020837 E-05	1.854386 E-04	0.0005
H2 =	9.379345 E-06	1.703791 E-04	0.0005
O =	3.358558 E-07	6.100939 E-06	0.0000
H =	3.602383 E-08	6.543855 E-07	0.0000
MnO2(s) =	5.311743 E-09	9.648968 E-08	0.0000
CH4 =	3.240546 E-11	5.886566 E-10	0.0000
CH3OH =	3.002025 E-11	5.453284 E-10	0.0000
HCN =	1.701938 E-11	3.091631 E-10	0.0000
CNO =	1.568492 E-11	2.849220 E-10	0.0000
CHNO =	7.709203 E-12	1.400404 E-10	0.0000
NH2 =	6.673415 E-12	1.212249 E-10	0.0000
N =	6.405651 E-12	1.163609 E-10	0.0000
NH3 =	1.730452 E-12	3.143428 E-11	0.0000

*Calculation for **F2** with H_2O_2 (95%)*

Combustion condition:

Isobaric combustion (p=const.)
Chamber pressure = 7.000 MPa
Ambient pressure = 0.100 MPa
Expansion conditions: Equilibrium expansion

Reactant information:

1. Water (H2O, liquid), 2.67%
2. Hydrogen peroxide (H2O2), 50.81%
3. **Mn-Gu**, 11.63%
4. NCH4, 34.89%

C(0.609) H(2.641) N(0.361) O(2.561) Mn(0.016)

Molecular weight = 56.89
Oxygen balance = 0.1574849 %
Enthalpy of formation = -5293.60 kJ/kg
Internal energy of formation = -5172.41 kJ/kg

Parameters in combustion chamber:

- Heat of isobaric combustion = -4235.08 kJ/kg
- Total enthalpy of combustion prod. = -5293.60 kJ/kg
- Entropy of combustion products = 10.04 kJ/K kg
- Isobaric combustion temperature = 2678.2 K
- Mole number of gaseous products = 37.862 mol/kg expl.
- Total mole number of products = 38.146 mol/kg expl.
- Volume of gaseous products (at SATP) = 938.56 L/kg expl.
- Mass of gaseous products = 979.9 g/kg expl.
- Mass of condensed products = 20.2 g/kg expl.
- Mean molecular mass of gaseous prod. = 25.880 g
- Mean molecular mass of all products = 26.216 g
- Specific gas constant = 314.783 J/kg K
- Specific heat capacity at p=const. (Cp) = 2059.22 J/kgK
- Specific heat capacity at V=const. (Cv) = 1744.44 J/molK
- Specific heat ratio (Cp/Cv) = 1.1804

Composition of combustion products in chamber:

Products	mol/mol	mol/kg	Mol %
H2O =	1.292457 E00	2.271914 E01	59.5584
CO2 =	5.578456 E-01	9.805959 E00	25.7064
N2 =	1.773242 E-01	3.117052 E00	8.1714
CO =	5.131595 E-02	9.020454 E-01	2.3647
O2 =	2.817961 E-02	4.953488 E-01	1.2986
OH =	2.196887 E-02	3.861746 E-01	1.0124
H2 =	1.668573 E-02	2.933062 E-01	0.7689
MnO(s) =	1.616737 E-02	2.841944 E-01	0.7450
NO =	5.908274 E-03	1.038572 E-01	0.2723
H =	1.241995 E-03	2.183212 E-02	0.0572
O =	9.710924 E-04	1.707012 E-02	0.0447
NH3 =	3.115468 E-07	5.476452 E-06	0.0000
N =	7.409492 E-08	1.302460 E-06	0.0000

NH2 =	6.746583 E-08	1.185932 E-06	0.0000
CHNO =	2.845893 E-08	5.002587 E-07	0.0000
HCN =	2.368334 E-09	4.163121 E-08	0.0000
CNO =	8.602596 E-10	1.512187 E-08	0.0000
MnO2(s) =	1.686302 E-13	2.964226 E-12	0.0000

Parameters at the nozzle throat:

- Total enthalpy of combustion prod. = -5758.24 kJ/kg
- Temperature at nozzle throat = 2512.4 K
- Pressure at nozzle throat = 4.0 MPa
- Mole number of gaseous products = 37.642 mol/kg expl.
- Total mole number of products = 37.926 mol/kg expl.
- Volume of gaseous products (at SATP) = 933.11 L/kg expl.
- Mass of gaseous products = 979.9 g/kg expl.
- Mass of condensed products = 20.2 g/kg expl.
- Mean molecular mass of gaseous prod. = 26.031 g
- Mean molecular mass of all products = 26.367 g
- Specific gas constant = 312.956 J/kg K
- Specific heat capacity at p=const. (Cp) = 2036.98 J/kgK
- Specific heat capacity at V=const. (Cv) = 1724.02 J/molK
- Specific heat ratio (Cp/Cv) = 1.1815

Characteristic parameters at the nozzle throat:

- Flow velocity at nozzle throat = 964.0 m/s
- Sound velocity at throat = 963.8 m/s
- Mach number at nozzle throat = 1.000
- Critical pressure ratio (pt/pc) = 0.565
- Pressure ratio (pc/pt) = 1.769

Composition of combustion products at nozzle throat:

Products	mol/mol	mol/kg	Mol %
H2O =	1.300911 E00	2.286776 E01	60.2954
CO2 =	5.734175 E-01	1.007969 E01	26.5771
N2 =	1.783312 E-01	3.134753 E00	8.2654
CO =	3.574402 E-02	6.283179 E-01	1.6567
O2 =	2.108325 E-02	3.706070 E-01	0.9772
MnO(s) =	1.616737 E-02	2.841944 E-01	0.7493
OH =	1.459895 E-02	2.566243 E-01	0.6766
H2 =	1.218058 E-02	2.141134 E-01	0.5646
NO =	3.894672 E-03	6.846157 E-02	0.1805
H =	7.141284 E-04	1.255314 E-02	0.0331
O =	5.210054 E-04	9.158371 E-03	0.0241
NH3 =	1.295304 E-07	2.276920 E-06	0.0000
N =	2.363510 E-08	4.154640 E-07	0.0000
NH2 =	2.156608 E-08	3.790944 E-07	0.0000
CHNO =	9.227276 E-09	1.621995 E-07	0.0000
HCN =	5.811988 E-10	1.021647 E-08	0.0000
CNO =	1.960964 E-10	3.447036 E-09	0.0000
MnO2(s) =	1.584323 E-13	2.784965 E-12	0.0000

Parameters at the nozzle exit:

- Total enthalpy of combustion prod. = -8028.77 kJ/kg
- Temperature at nozzle exit = 1488.0 K
- Pressure at nozzle throat = 0.1 MPa
- Mole number of gaseous products = 37.143 mol/kg expl.

- Total mole number of products = 37.427 mol/kg expl.
- Volume of gaseous products (at SATP) = 920.74 L/kg expl.
- Mass of gaseous products = 979.9 g/kg expl.
- Mass of condensed products = 20.2 g/kg expl.
- Mean molecular mass of gaseous prod. = 26.381 g
- Mean molecular mass of all products = 26.719 g
- Specific gas constant = 308.807 J/kg K
- Specific heat capacity at p=const. (Cp) = 1819.97 J/kgK
- Specific heat capacity at V=const. (Cv) = 1511.16 J/molK
- Specific heat ratio (Cp/Cv) = 1.2044

Characteristic parameters at the nozzle exit:
- Specific impulse = 238.42 s
- Exhaust (or nozzle exit) velocity = 2338.9 m/s
- Characteristic exhaust velocity (c*) = 1400.5 m/s
- Thrust coefficient (Cf) = 1.670
- Nozzle area expansion ratio (Ae/At) = 8.98
- Pressure ratio (pc/pe) = 70.000
- Sound velocity at nozzle exit = 736.83 m/s
- Mach number at nozzle exit = 3.174

Composition of combustion products at the nozzle exit:

Products	mol/mol	mol/kg	Mol %
H2O =	1.320718 E00	2.321593 E01	62.0296
CO2 =	6.091585 E-01	1.070795 E01	28.6101
N2 =	1.802515 E-01	3.168508 E00	8.4658
MnO(s) =	1.616738 E-02	2.841946 E-01	0.7593
O2 =	2.762435 E-03	4.855881 E-02	0.1297
NO =	5.425690 E-05	9.537421 E-04	0.0025
OH =	5.402444 E-05	9.496560 E-04	0.0025
H2 =	3.502851 E-06	6.157404 E-05	0.0002
CO =	3.045565 E-06	5.353576 E-05	0.0001
O =	2.153162 E-07	3.784886 E-06	0.0000
H =	4.816059 E-08	8.465797 E-07	0.0000
MnO2(s) =	1.274634 E-09	2.240586 E-08	0.0000
NH3 =	1.741229 E-12	3.060778 E-11	0.0000
CNO =	8.894704 E-14	1.563535 E-12	0.0000
HCN =	8.889933 E-14	1.562696 E-12	0.0000
CHNO =	9.053860 E-15	1.591512 E-13	0.0000
N =	5.913621 E-15	1.039512 E-13	0.0000
NH2 =	2.415089 E-15	4.245307 E-14	0.0000

*Calculation for **F3** with H_2O_2 (95%)*

Combustion condition:

Isobaric combustion (p=const.)
Chamber pressure = 7.000 MPa
Ambient pressure = 0.100 MPa
Expansion conditions: Equilibrium expansion

Reactant information:

1. Water (H2O, liquid), 2.62%
2. Hydrogen peroxide (H2O2), 49.77%
3. **Mn-Gu**, 9.52%

4. NCH4, 38.09%

C(0.632) H(2.659) N(0.356) O(2.619) Mn(0.013)

Molecular weight = 57.89
Oxygen balance = 0.3472458%
Enthalpy of formation = -5254.34 kJ/kg
Internal energy of formation = -5133.73 kJ/kg

Parameters in combustion chamber:

- Heat of isobaric combustion = -4259.54 kJ/kg
- Total enthalpy of combustion prod. = -5255.08 kJ/kg
- Entropy of combustion products = 10.04 kJ/K kg
- Isobaric combustion temperature = 2694.8 K
- Mole number of gaseous products = 37.800 mol/kg expl.
- Total mole number of products = 38.033 mol/kg expl.
- Volume of gaseous products (at SATP) = 937.02 L/kg expl.
- Mass of gaseous products = 983.5 g/kg expl.
- Mass of condensed products = 16.5 g/kg expl.
- Mean molecular mass of gaseous prod. = 26.019 g
- Mean molecular mass of all products = 26.294 g
- Specific gas constant = 314.269 J/kg K
- Specific heat capacity at p=const. (Cp) = 2055.30 J/kgK
- Specific heat capacity at V=const. (Cv) = 1741.03 J/molK
- Specific heat ratio (Cp/Cv) = 1.1805

Composition of combustion products in chamber:

Products	mol/mol	mol/kg	Mol %
H2O =	1.299798 E00	2.245188 E01	59.0332
CO2 =	5.778342 E-01	9.981136 E00	26.2436
N2 =	1.745963 E-01	3.015863 E00	7.9297
CO =	5.399708 E-02	9.327108 E-01	2.4524
O2 =	3.231866 E-02	5.582516 E-01	1.4678
OH =	2.394252 E-02	4.135676 E-01	1.0874
H2 =	1.694114 E-02	2.926303 E-01	0.7694
MnO(s) =	1.346778 E-02	2.326337 E-01	0.6117
NO =	6.441925 E-03	1.112737 E-01	0.2926
H =	1.344226 E-03	2.321929 E-02	0.0611
O =	1.125569 E-03	1.944236 E-02	0.0511
NH3 =	3.068363 E-07	5.300093 E-06	0.0000
N =	8.471135 E-08	1.463249 E-06	0.0000
NH2 =	7.097507 E-08	1.225978 E-06	0.0000
CHNO =	2.960062 E-08	5.113021 E-07	0.0000
HCN =	2.476807 E-09	4.278277 E-08	0.0000
CNO =	9.639640 E-10	1.665089 E-08	0.0000
MnO2(s) =	1.730650 E-13	2.989414 E-12	0.0000

Parameters at the nozzle throat:

- Total enthalpy of combustion prod. = -5722.23 kJ/kg
- Temperature at nozzle throat = 2529.5 K
- Pressure at nozzle throat = 4.0 MPa
- Mole number of gaseous products = 37.573 mol/kg expl.
- Total mole number of products = 37.806 mol/kg expl.
- Volume of gaseous products (at SATP) = 931.40 L/kg expl.
- Mass of gaseous products = 983.5 g/kg expl.

- Mass of condensed products = 16.5 g/kg expl.
- Mean molecular mass of gaseous prod. = 26.176 g
- Mean molecular mass of all products = 26.452 g
- Specific gas constant = 312.382 J/kg K
- Specific heat capacity at p=const. (Cp) = 2033.62 J/kgK
- Specific heat capacity at V=const. (Cv) = 1721.23 J/molK
- Specific heat ratio (Cp/Cv) = 1.1815

Characteristic parameters at the nozzle throat:
- Flow velocity at nozzle throat = 966.6 m/s
- Sound velocity at throat) = 966.2 m/s
- Mach number at nozzle throat = 1.000
- Critical pressure ratio (pt/pc) = 0.565
- Pressure ratio (pc/pt) = 1.769

Composition of combustion products at nozzle throat:

Products	mol/mol	mol/kg	Mol %
H2O =	1.308583 E00	2.260363 E01	59.7891
CO2 =	5.942634 E-01	1.026492 E01	27.1519
N2 =	1.756524 E-01	3.034106 E00	8.0255
CO =	3.756791 E-02	6.489239 E-01	1.7165
O2 =	2.491352 E-02	4.303401 E-01	1.1383
OH =	1.615571 E-02	2.790633 E-01	0.7382
MnO(s) =	1.346778 E-02	2.326337 E-01	0.6153
H2 =	1.233199 E-02	2.130149 E-01	0.5634
NO =	4.330024 E-03	7.479404 E-02	0.1978
H =	7.801139 E-04	1.347518 E-02	0.0356
O =	6.204222 E-04	1.071677 E-02	0.0283
NH3 =	1.266853 E-07	2.188281 E-06	0.0000
N =	2.764398 E-08	4.775044 E-07	0.0000
NH2 =	2.282091 E-08	3.941938 E-07	0.0000
CHNO =	9.577774 E-09	1.654403 E-07	0.0000
HCN =	6.043770 E-10	1.043962 E-08	0.0000
CNO =	2.223687 E-10	3.841054 E-09	0.0000
MnO2(s) =	1.643019 E-13	2.838045 E-12	0.0000

Parameters at the nozzle exit:
- Total enthalpy of combustion prod. = -8006.68 kJ/kg
- Temperature at nozzle exit = 1501.9 K
- Pressure at nozzle throat = 0.1 MPa
- Mole number of gaseous products = 37.058 mol/kg expl.
- Total mole number of products = 37.291 mol/kg expl.
- Volume of gaseous products (at SATP) = 918.63 L/kg expl.
- Mass of gaseous products = 983.5 g/kg expl.
- Mass of condensed products = 16.5 g/kg expl.
- Mean molecular mass of gaseous prod. = 26.540 g
- Mean molecular mass of all products = 26.817 g
- Specific gas constant = 308.100 J/kg K
- Specific heat capacity at p=const. (Cp) = 1819.35 J/kgK
- Specific heat capacity at V=const. (Cv) = 1511.25 J/molK
- Specific heat ratio (Cp/Cv) = 1.2039

Characteristic parameters at the nozzle exit:
- Specific impulse = 239.13 s
- Exhaust (or nozzle exit) velocity = 2345.9 m/s

- Characteristic exhaust velocity (c*) = 1403.4 m/s
- Thrust coefficient (Cf) = 1.672
- Nozzle area expansion ratio (Ae/At) = 8.99
- Pressure ratio (pc/pe) = 70.000
- Sound velocity at nozzle exit = 739.41 m/s
- Mach number at nozzle exit = 3.173

Composition of combustion products at the nozzle exit:

Products	mol/mol	mol/kg	Mol %
H2O =	1.329291 E00	2.296132 E01	61.5740
CO2 =	6.317888 E-01	1.091311 E01	29.2651
N2 =	1.777681 E-01	3.070651 E00	8.2344
MnO(s) =	1.346778 E-02	2.326337 E-01	0.6238
O2 =	6.240214 E-03	1.077894 E-01	0.2891
OH =	1.204176 E-04	2.080016 E-03	0.0056
NO =	9.880341 E-05	1.706666 E-03	0.0046
CO =	4.257420 E-05	7.353993 E-04	0.0020
H2 =	3.211845 E-05	5.547933 E-04	0.0015
O =	4.862837 E-07	8.399752 E-06	0.0000
H =	1.769272 E-07	3.056127 E-06	0.0000
NH3 =	1.069915 E-12	1.848103 E-11	0.0000
MnO2(s) =	4.459390 E-13	7.702863 E-12	0.0000
NH2 =	2.182875 E-14	3.770558 E-13	0.0000
N =	2.070894 E-14	3.577129 E-13	0.0000
CHNO =	1.431382 E-14	2.472477 E-13	0.0000
CNO =	5.583402 E-18	9.644409 E-17	0.0000
HCN =	3.372374 E-18	5.825222 E-17	0.0000

*Calculation for **F4** with H_2O_2 (95%)*

Combustion condition:

Isobaric combustion (p=const.)
Chamber pressure = 7.000 MPa
Ambient pressure = 0.100 MPa
Expansion conditions: Equilibrium expansion

Reactant information:

1. Water (H2O, liquid), 2.5%
2. Hydrogen peroxide (H2O2), 47.5%
3. **Mn-Gu**, 7.5%
4. NCH4, 42.5%

C(0.688) H(2.710) N(0.367) O(2.719) Mn(0.011)

Molecular weight = 60.24
Oxygen balance = -0.5831683%
Enthalpy of formation = -5191.68 kJ/kg
Internal energy of formation = -5072.43 kJ/kg

Parameters in combustion chamber:

- Heat of isobaric combustion = -4292.69 kJ/kg
- Total enthalpy of combustion prod. = -5192.61 kJ/kg
- Entropy of combustion products = 10.03 kJ/K kg
- Isobaric combustion temperature = 2721.0 K
- Mole number of gaseous products = 37.684 mol/kg expl.

- Total mole number of products = 37.867 mol/kg expl.
- Volume of gaseous products (at SATP) = 934.15 L/kg expl.
- Mass of gaseous products = 987.0 g/kg expl.
- Mass of condensed products = 13.0 g/kg expl.
- Mean molecular mass of gaseous prod. = 26.192 g
- Mean molecular mass of all products = 26.409 g
- Specific gas constant = 313.304 J/kg K
- Specific heat capacity at p=const. (Cp) = 2046.70 J/kgK
- Specific heat capacity at V=const. (Cv) = 1733.40 J/molK
- Specific heat ratio (Cp/Cv) = 1.1807

Composition of combustion products in chamber:

Products	mol/mol	mol/kg	Mol %
H2O =	1.320039 E00	2.191328 E01	57.8688
CO2 =	6.150190 E-01	1.020961 E01	26.9616
N2 =	1.803761 E-01	2.994330 E00	7.9075
CO =	7.258049 E-02	1.204871 E00	3.1818
O2 =	2.661354 E-02	4.417977 E-01	1.1667
OH =	2.485503 E-02	4.126056 E-01	1.0896
H2 =	2.152164 E-02	3.572696 E-01	0.9435
MnO(s) =	1.104018 E-02	1.832724 E-01	0.4840
NO =	6.181247 E-03	1.026117 E-01	0.2710
H =	1.702685 E-03	2.826540 E-02	0.0746
O =	1.161061 E-03	1.927417 E-02	0.0509
NH3 =	4.181925 E-07	6.942197 E-06	0.0000
N =	1.078557 E-07	1.790457 E-06	0.0000
NH2 =	9.740276 E-08	1.616933 E-06	0.0000
CHNO =	4.425609 E-08	7.346724 E-07	0.0000
HCN =	4.596999 E-09	7.631240 E-08	0.0000
CNO =	1.459776 E-09	2.423298 E-08	0.0000
CH3OH =	6.596911 E-13	1.095119 E-11	0.0000
MnO2(s) =	1.466695 E-13	2.434784 E-12	0.0000

Parameters at the nozzle throat:
- Total enthalpy of combustion prod. = -5662.32 kJ/kg
- Temperature at nozzle throat = 2556.6 K
- Pressure at nozzle throat = 4.0 MPa
- Mole number of gaseous products = 37.447 mol/kg expl.
- Total mole number of products = 37.630 mol/kg expl.
- Volume of gaseous products (at SATP) = 928.26 L/kg expl.
- Mass of gaseous products = 987.0 g/kg expl.
- Mass of condensed products = 13.0 g/kg expl.
- Mean molecular mass of gaseous prod. = 26.358 g
- Mean molecular mass of all products = 26.575 g
- Specific gas constant = 311.331 J/kg K
- Specific heat capacity at p=const. (Cp) = 2025.94 J/kgK
- Specific heat capacity at V=const. (Cv) = 1714.61 J/molK
- Specific heat ratio (Cp/Cv) = 1.1816

Characteristic parameters at the nozzle throat:
- Flow velocity at nozzle throat = 969.2 m/s
- Sound velocity at throat = 969.8 m/s
- Mach number at nozzle throat = 0.999
- Critical pressure ratio (pt/pc) = 0.566
- Pressure ratio (pc/pt) = 1.768

Composition of combustion products at nozzle throat:

Products	mol/mol	mol/kg	Mol %
H2O =	1.329229 E00	2.206585 E01	58.6391
CO2 =	6.332125 E-01	1.051163 E01	27.9343
N2 =	1.814823 E-01	3.012695 E00	8.0061
CO =	5.438696 E-02	9.028498 E-01	2.3993
O2 =	1.845762 E-02	3.064054 E-01	0.8143
H2 =	1.682133 E-02	2.792422 E-01	0.7421
OH =	1.653748 E-02	2.745301 E-01	0.7296
MnO(s) =	1.104018 E-02	1.832724 E-01	0.4870
NO =	3.969149 E-03	6.588978 E-02	0.1751
H =	1.040598 E-03	1.727442 E-02	0.0459
O =	6.184362 E-04	1.026634 E-02	0.0273
NH3 =	1.927950 E-07	3.200490 E-06	0.0000
N =	3.644814 E-08	6.050566 E-07	0.0000
NH2 =	3.410536 E-08	5.661655 E-07	0.0000
CHNO =	1.600929 E-08	2.657619 E-07	0.0000
HCN =	1.346959 E-09	2.236017 E-08	0.0000
CNO =	3.705518 E-10	6.151339 E-09	0.0000
MnO2(s) =	1.307238 E-13	2.170079 E-12	0.0000
CH3OH =	1.271757 E-13	2.111179 E-12	0.0000

Parameters at the nozzle exit:

- Total enthalpy of combustion prod. = -7963.50 kJ/kg
- Temperature at nozzle exit = 1511.8 K
- Pressure at nozzle throat = 0.1 MPa
- Mole number of gaseous products = 36.951 mol/kg expl.
- Total mole number of products = 37.135 mol/kg expl.
- Volume of gaseous products (at SATP) = 915.98 L/kg expl.
- Mass of gaseous products = 987.0 g/kg expl.
- Mass of condensed products = 13.0 g/kg expl.
- Mean molecular mass of gaseous prod. = 26.711 g
- Mean molecular mass of all products = 26.930 g
- Specific gas constant = 307.213 J/kg K
- Specific heat capacity at p=const. (Cp) = 1813.45 J/kgK
- Specific heat capacity at V=const. (Cv) = 1506.24 J/molK
- Specific heat ratio (Cp/Cv) = 1.2040

Characteristic parameters at the nozzle exit:

- Specific impulse = 239.97 s
- Exhaust (or nozzle exit) velocity = 2354.1 m/s
- Characteristic exhaust velocity (c*) = 1408.1 m/s
- Thrust coefficient (Cf) = 1.672
- Nozzle area expansion ratio (Ae/At) = 8.99
- Pressure ratio (pc/pe) = 70.000
- Sound velocity at nozzle exit = 740.79 m/s
- Mach number at nozzle exit = 3.178

Composition of combustion products at the nozzle exit:

Products	mol/mol	mol/kg	Mol %
H2O =	1.345729 E00	2.233976 E01	60.1590
CO2 =	6.747399 E-01	1.120101 E01	30.1633

N2 =	1.834667 E-01	3.045637 E00	8.2016
CO =	1.285955 E-02	2.134748 E-01	0.5749
MnO(s) =	1.104018 E-02	1.832724 E-01	0.4935
H2 =	9.103233 E-03	1.511181 E-01	0.4069
OH =	1.187582 E-05	1.971444 E-04	0.0005
H =	2.986340 E-06	4.957468 E-05	0.0001
NO =	6.275183 E-07	1.041711 E-05	0.0000
O2 =	1.801717 E-07	2.990937 E-06	0.0000
NH3 =	1.257742 E-08	2.087913 E-07	0.0000
O =	2.601021 E-09	4.317820 E-08	0.0000
CHNO =	4.402079 E-11	7.307663 E-10	0.0000
NH2 =	7.563998 E-12	1.255660 E-10	0.0000
HCN =	2.504553 E-13	4.157679 E-12	0.0000
N =	5.242542 E-15	8.702873 E-14	0.0000
MnO2(s) =	2.177165 E-15	3.614199 E-14	0.0000
CNO =	1.550810 E-15	2.574419 E-14	0.0000
CH3OH =	1.471250 E-16	2.442346 E-15	0.0000

*Calculation for **F8** with H_2O_2 (95%)*

Combustion condition:

Isobaric combustion (p=const.)
Chamber pressure = 7.000 MPa
Ambient pressure = 0.100 MPa
Expansion conditions: Equilibrium expansion

Reactant information:

1. Cu-Gu, 13.95 %
2. Hydrogen peroxide (H_2O_2), 50.82%
3. Water (H_2O, liquid), 2.67%
4. NCH4, 32.56%

C(0.608) H(2.646) N(0.376) O(2.530) Cu(0.019)

Molecular weight = 56.91
Oxygen balance = -0.7783484%
Enthalpy of formation = -5287.28 kJ/kg
Internal energy of formation = -5166.39 kJ/kg

Parameters in combustion chamber:

- Heat of isobaric combustion = -4076.63 kJ/kg
- Total enthalpy of combustion prod. = -5287.03 kJ/kg
- Entropy of combustion products = 9.98 kJ/K kg
- Isobaric combustion temperature = 2611.6 K
- Mole number of gaseous products = 38.083 mol/kg expl.
- Total mole number of products = 38.103 mol/kg expl.
- Volume of gaseous products (at SATP) = 944.05 L/kg expl.
- Mass of gaseous products = 998.8 g/kg expl.
- Mass of condensed products = 1.2 g/kg expl.
- Mean molecular mass of gaseous prod. = 26.227 g
- Mean molecular mass of all products = 26.245 g
- Specific gas constant = 316.625 J/kg K
- Specific heat capacity at p=const. (Cp) = 2039.66 J/kgK
- Specific heat capacity at V=const. (Cv) = 1723.04 J/molK

- Specific heat ratio (Cp/Cv) = 1.1838

Composition of combustion products in chamber:

Products	mol/mol	mol/kg	Mol %
H2O =	1.298838 E00	2.282383 E01	59.9010
CO2 =	5.619494 E-01	9.874860 E00	25.9165
N2 =	1.855800 E-01	3.261106 E00	8.5587
CO =	4.578279 E-02	8.045183 E-01	2.1115
O2 =	1.925134 E-02	3.382942 E-01	0.8879
Cu =	1.703656 E-02	2.993751 E-01	0.7857
OH =	1.665817 E-02	2.927259 E-01	0.7683
H2 =	1.523989 E-02	2.678030 E-01	0.7028
NO =	4.493395 E-03	7.896021 E-02	0.2072
Cu(s) =	1.092979 E-03	1.920638 E-02	0.0504
H =	9.161180 E-04	1.609849 E-02	0.0423
CuO =	8.695670 E-04	1.528047 E-02	0.0401
O =	6.003606 E-04	1.054984 E-02	0.0277
NH3 =	2.936731 E-07	5.160573 E-06	0.0000
NH2 =	5.088753 E-08	8.942214 E-07	0.0000
N =	4.380576 E-08	7.697770 E-07	0.0000
CHNO =	2.424225 E-08	4.259970 E-07	0.0000
Cu2O(s) =	7.226236 E-09	1.269831 E-07	0.0000
HCN =	1.864552 E-09	3.276485 E-08	0.0000
CNO =	5.662764 E-10	9.950896 E-09	0.0000
CuO(s) =	4.977290 E-12	8.746346 E-11	0.0000
CH3OH =	2.725072 E-13	4.788635 E-12	0.0000
Cu(OH)2(s) =	2.543617 E-14	4.469772 E-13	0.0000

Parameters at the nozzle throat:

- Total enthalpy of combustion prod. = -5742.70 kJ/kg
- Temperature at nozzle throat = 2449.3 K
- Pressure at nozzle throat = 3.9 MPa
- Mole number of gaseous products = 37.832 mol/kg expl.
- Total mole number of products = 37.920 mol/kg expl.
- Volume of gaseous products (at SATP) = 937.81 L/kg expl.
- Mass of gaseous products = 994.4 g/kg expl.
- Mass of condensed products = 5.6 g/kg expl.
- Mean molecular mass of gaseous prod. = 26.285 g
- Mean molecular mass of all products = 26.372 g
- Specific gas constant = 314.533 J/kg K
- Specific heat capacity at p=const. (Cp) = 2019.09 J/kgK
- Specific heat capacity at V=const. (Cv) = 1704.55 J/molK
- Specific heat ratio (Cp/Cv) = 1.1845

Characteristic parameters at the nozzle throat:

- Flow velocity at nozzle throat = 954.6 m/s
- Sound velocity at throat) = 955.3 m/s
- Mach number at nozzle throat = 0.999
- Critical pressure ratio (pt/pc) = 0.564
- Pressure ratio (pc/pt) = 1.773

Composition of combustion products at nozzle throat:

Products	mol/mol	mol/kg	Mol %
H2O =	1.305898 E00	2.294790 E01	60.5162
CO2 =	5.753453 E-01	1.011026 E01	26.6619
N2 =	1.864212 E-01	3.275888 E00	8.6389
CO =	3.238693 E-02	5.691195 E-01	1.5008
Cu =	1.348737 E-02	2.370070 E-01	0.6250
O2 =	1.320160 E-02	2.319852 E-01	0.6118
H2 =	1.136773 E-02	1.997594 E-01	0.5268
OH =	1.067549 E-02	1.875950 E-01	0.4947
Cu(s) =	5.035790 E-03	8.849145 E-02	0.2334
NO =	2.811242 E-03	4.940056 E-02	0.1303
H =	5.227345 E-04	9.185756 E-03	0.0242
CuO =	4.759613 E-04	8.363833 E-03	0.0221
O =	3.019093 E-04	5.305303 E-03	0.0140
NH3 =	1.264783 E-07	2.222540 E-06	0.0000
NH2 =	1.634036 E-08	2.871411 E-07	0.0000
N =	1.341297 E-08	2.356995 E-07	0.0000
CHNO =	8.045220 E-09	1.413747 E-07	0.0000
HCN =	4.795132 E-10	8.426248 E-09	0.0000
CNO =	1.279123 E-10	2.247740 E-09	0.0000
Cu2O(s) =	1.095633 E-10	1.925303 E-09	0.0000
CuO(s) =	5.561570 E-12	9.773072 E-11	0.0000
CH3OH =	4.545801 E-14	7.988111 E-13	0.0000
Cu(OH)2(s) =	1.707789 E-14	3.001012 E-13	0.0000

Parameters at the nozzle exit:

- Total enthalpy of combustion prod. = -7962.74 kJ/kg
- Temperature at nozzle exit = 1443.1 K
- Pressure at nozzle throat = 0.1 MPa
- Mole number of gaseous products = 37.226 mol/kg expl.
- Total mole number of products = 37.560 mol/kg expl.
- Volume of gaseous products (at SATP) = 922.80 L/kg expl.
- Mass of gaseous products = 978.8 g/kg expl.
- Mass of condensed products = 21.2 g/kg expl.
- Mean molecular mass of gaseous prod. = 26.294 g
- Mean molecular mass of all products = 26.625 g
- Specific gas constant = 309.499 J/kg K
- Specific heat capacity at p=const. (Cp) = 1802.56 J/kgK
- Specific heat capacity at V=const. (Cv) = 1493.06 J/molK
- Specific heat ratio (Cp/Cv) = 1.2073

Characteristic parameters at the nozzle exit:

- Specific impulse = 235.81 s
- Exhaust (or nozzle exit) velocity = 2313.3 m/s
- Characteristic exhaust velocity (c*) = 1383.3 m/s
- Thrust coefficient (Cf) = 1.672
- Nozzle area expansion ratio (Ae/At) = 8.93
- Pressure ratio (pc/pe) = 70.000
- Sound velocity at nozzle exit = 727.36 m/s
- Mach number at nozzle exit = 3.180

Composition of combustion products at the nozzle exit:

Products	mol/mol	mol/kg	Mol %
H2O =	1.318817 E00	2.317491 E01	61.7011
CO2 =	6.030887 E-01	1.059778 E01	28.2156
N2 =	1.878268 E-01	3.300587 E00	8.7875
Cu(s) =	1.899284 E-02	3.337519 E-01	0.8886
CO =	4.643571 E-03	8.159918 E-02	0.2173
H2 =	4.045522 E-03	7.108997 E-02	0.1893
Cu =	6.293644 E-06	1.105951 E-04	0.0003
OH =	5.604807 E-06	9.849051 E-05	0.0003
H =	8.684090 E-07	1.526012 E-05	0.0000
NO =	3.104920 E-07	5.456122 E-06	0.0000
O2 =	1.179973 E-07	2.073509 E-06	0.0000
NH3 =	4.685246 E-09	8.233151 E-08	0.0000
O =	9.094133 E-10	1.598067 E-08	0.0000
Cu2O(s) =	6.085407 E-10	1.069359 E-08	0.0000
CuO =	2.166718 E-10	3.807466 E-09	0.0000
CH3OH =	1.436203 E-10	2.523769 E-09	0.0000
Cu(OH)2(s) =	1.282125 E-10	2.253014 E-09	0.0000
CNO =	1.194061 E-10	2.098265 E-09	0.0000
N =	8.679519 E-11	1.525209 E-09	0.0000
HCN =	4.311832 E-11	7.576970 E-10	0.0000
CuO(s) =	4.268487 E-11	7.500802 E-10	0.0000
NH2 =	2.974849 E-11	5.227556 E-10	0.0000
CHNO =	9.739424 E-12	1.711461 E-10	0.0000

*Calculation for **F9** with H_2O_2 (95%)*

Combustion condition:

Isobaric combustion (p=const.)
Chamber pressure = 7.000 MPa
Ambient pressure = 0.100 MPa
Expansion conditions: Equilibrium expansion

Reactant information:

1. Cu-Gu, 11.9 %
2. Hydrogen peroxide (H_2O_2), 49.77%
3. Water (H_2O, liquid), 2.62%
4. NCH4, 35.71%

C(0.631) H(2.664) N(0.372) O(2.587) Cu(0.016)

Molecular weight = 57.92
Oxygen balance = -0.6661997%
Enthalpy of formation = -5252.60 kJ/kg
Internal energy of formation = -5132.27 kJ/kg

Parameters in combustion chamber:

- Heat of isobaric combustion = -4120.97 kJ/kg
- Total enthalpy of combustion prod. = -5252.57 kJ/kg
- Entropy of combustion products = 9.99 kJ/K kg
- Isobaric combustion temperature = 2636.8 K
- Mole number of gaseous products = 37.997 mol/kg expl.

- Total mole number of products = 38.000 mol/kg expl.
- Volume of gaseous products (at SATP) = 941.92 L/kg expl.
- Mass of gaseous products = 999.9 g/kg expl.
- Mass of condensed products = 0.1 g/kg expl.
- Mean molecular mass of gaseous prod. = 26.314 g
- Mean molecular mass of all products = 26.317 g
- Specific gas constant = 315.910 J/kg K
- Specific heat capacity at p=const. (Cp) = 2038.33 J/kgK
- Specific heat capacity at V=const. (Cv) = 1722.42 J/molK
- Specific heat ratio (Cp/Cv) = 1.1834

Composition of combustion products in chamber:

Products	mol/mol	mol/kg	Mol %
H2O =	1.306108 E00	2.255114 E01	59.3457
CO2 =	5.807665 E-01	1.002746 E01	26.3883
N2 =	1.836135 E-01	3.170253 E00	8.3429
CO =	5.047369 E-02	8.714738 E-01	2.2934
O2 =	2.187948 E-02	3.777689 E-01	0.9941
OH =	1.858857 E-02	3.209484 E-01	0.8446
H2 =	1.618560 E-02	2.794590 E-01	0.7354
Cu =	1.554050 E-02	2.683208 E-01	0.7061
NO =	4.962280 E-03	8.567825 E-02	0.2255
H =	1.052045 E-03	1.816451 E-02	0.0478
CuO =	8.266984 E-04	1.427369 E-02	0.0376
O =	7.217743 E-04	1.246209 E-02	0.0328
Cu(s) =	1.277408 E-04	2.205561 E-03	0.0058
NH3 =	3.072707 E-07	5.305306 E-06	0.0000
NH2 =	5.784424 E-08	9.987331 E-07	0.0000
N =	5.425311 E-08	9.367290 E-07	0.0000
CHNO =	2.711786 E-08	4.682143 E-07	0.0000
HCN =	2.188016 E-09	3.777807 E-08	0.0000
CNO =	6.976258 E-10	1.204514 E-08	0.0000
Cu2O(s) =	2.956257 E-11	5.104245 E-10	0.0000
CuO(s) =	3.559156 E-12	6.145204 E-11	0.0000
CH3OH =	2.971854 E-13	5.131175 E-12	0.0000
Cu(OH)2(s) =	1.927212 E-14	3.327506 E-13	0.0000

Parameters at the nozzle throat:

- Total enthalpy of combustion prod. = -5712.73 kJ/kg
- Temperature at nozzle throat = 2468.7 K
- Pressure at nozzle throat = 3.9 MPa
- Mole number of gaseous products = 37.785 mol/kg expl.
- Total mole number of products = 37.796 mol/kg expl.
- Volume of gaseous products (at SATP) = 936.65 L/kg expl.
- Mass of gaseous products = 999.3 g/kg expl.
- Mass of condensed products = 0.7 g/kg expl.
- Mean molecular mass of gaseous prod. = 26.447 g
- Mean molecular mass of all products = 26.458 g
- Specific gas constant = 314.144 J/kg K
- Specific heat capacity at p=const. (Cp) = 2015.57 J/kgK
- Specific heat capacity at V=const. (Cv) = 1701.43 J/molK
- Specific heat ratio (Cp/Cv) = 1.1846

Characteristic parameters at the nozzle throat:

- Flow velocity at nozzle throat = 959.3 m/s
- Sound velocity at throat) = 958.5 m/s
- Mach number at nozzle throat = 1.001
- Critical pressure ratio (pt/pc) = 0.561
- Pressure ratio (pc/pt) = 1.781

Composition of combustion products at nozzle throat:

Products	mol/mol	mol/kg	Mol %
H2O =	1.313959 E00	2.268669 E01	60.0234
CO2 =	5.958932 E-01	1.028863 E01	27.2212
N2 =	1.845490 E-01	3.186405 E00	8.4304
CO =	3.534697 E-02	6.102973 E-01	1.6147
Cu =	1.526883 E-02	2.636302 E-01	0.6975
O2 =	1.501751 E-02	2.592909 E-01	0.6860
H2 =	1.194311 E-02	2.062086 E-01	0.5456
OH =	1.183379 E-02	2.043211 E-01	0.5406
NO =	3.091568 E-03	5.337871 E-02	0.1412
Cu(s) =	6.646789 E-04	1.147628 E-02	0.0304
H =	5.911933 E-04	1.020749 E-02	0.0270
CuO =	5.614322 E-04	9.693635 E-03	0.0256
O =	3.590982 E-04	6.200155 E-03	0.0164
NH3 =	1.300063 E-07	2.244676 E-06	0.0000
NH2 =	1.814212 E-08	3.132401 E-07	0.0000
N =	1.622784 E-08	2.801883 E-07	0.0000
CHNO =	8.817961 E-09	1.522501 E-07	0.0000
HCN =	5.457339 E-10	9.422589 E-09	0.0000
CNO =	1.531611 E-10	2.644464 E-09	0.0000
Cu2O(s) =	8.937853 E-11	1.543201 E-09	0.0000
CuO(s) =	5.447177 E-12	9.405043 E-11	0.0000
CH3OH =	5.069396 E-14	8.752771 E-13	0.0000
Cu(OH)2(s) =	1.640580 E-14	2.832610 E-13	0.0000

Parameters at the nozzle exit:

- Total enthalpy of combustion prod. = -7953.85 kJ/kg
- Temperature at nozzle exit = 1467.5 K
- Pressure at nozzle throat = 0.1 MPa
- Mole number of gaseous products = 37.112 mol/kg expl.
- Total mole number of products = 37.397 mol/kg expl.
- Volume of gaseous products (at SATP) = 919.98 L/kg expl.
- Mass of gaseous products = 981.9 g/kg expl.
- Mass of condensed products = 18.1 g/kg expl.
- Mean molecular mass of gaseous prod. = 26.458 g
- Mean molecular mass of all products = 26.741 g
- Specific gas constant = 308.553 J/kg K
- Specific heat capacity at p=const. (Cp) = 1806.05 J/kgK
- Specific heat capacity at V=const. (Cv) = 1497.50 J/molK
- Specific heat ratio (Cp/Cv) = 1.2060

Characteristic parameters at the nozzle exit:

- Specific impulse = 236.94 s
- Exhaust (or nozzle exit) velocity = 2324.3 m/s
- Characteristic exhaust velocity (c*) = 1388.3 m/s
- Thrust coefficient (Cf) = 1.674
- Nozzle area expansion ratio (Ae/At) = 8.95
- Pressure ratio (pc/pe) = 70.000
- Sound velocity at nozzle exit = 732.40 m/s
- Mach number at nozzle exit = 3.174

Composition of combustion products at the nozzle exit:

Products	mol/mol	mol/kg	Mol %
H2O =	1.328698 E00	2.294117 E01	61.3448
CO2 =	6.270251 E-01	1.082615 E01	28.9492
N2 =	1.860945 E-01	3.213090 E00	8.5918
Cu(s) =	1.648500 E-02	2.846285 E-01	0.7611
CO =	4.215142 E-03	7.277824 E-02	0.1946
H2 =	3.412021 E-03	5.891163 E-02	0.1575
Cu =	9.949192 E-06	1.717818 E-04	0.0005
OH =	9.167227 E-06	1.582805 E-04	0.0004
H =	1.110572 E-06	1.917504 E-05	0.0001
NO =	6.788745 E-07	1.172138 E-05	0.0000
O2 =	2.866030 E-07	4.948460 E-06	0.0000
NH3 =	2.864533 E-09	4.945876 E-08	0.0000
O =	1.909838 E-09	3.297507 E-08	0.0000
CuO =	7.978281 E-10	1.377522 E-08	0.0000
Cu2O(s) =	5.535676 E-10	9.557845 E-09	0.0000
CH3OH =	1.492301 E-10	2.576592 E-09	0.0000
Cu(OH)2(s) =	1.257715 E-10	2.171559 E-09	0.0000
CNO =	1.165205 E-10	2.011832 E-09	0.0000
N =	8.014578 E-11	1.383789 E-09	0.0000
HCN =	4.653634 E-11	8.034919 E-10	0.0000
CuO(s) =	3.976983 E-11	6.866621 E-10	0.0000
NH2 =	2.885263 E-11	4.981668 E-10	0.0000
CHNO =	1.138343 E-11	1.965451 E-10	0.0000

*Calculation for **F10** with H_2O_2 (95%)*

Combustion condition:
Isobaric combustion (p=const.)
Chamber pressure = 7.000 MPa
Ambient pressure = 0.100 MPa
Expansion conditions: Equilibrium expansion

Reactant information:

1. Water (H_2O, liquid), 3%
2. Hydrogen peroxide (H_2O_2), 57%
3. NCH4, 30%
4. JN-15, 10%

C(0.527) H(2.574) N(0.302) O(2.375) Fe(0.015)

Molecular weight = 51.96
Oxygen balance = 0.3861742%
Enthalpy of formation = -4827.41 kJ/kg
Internal energy of formation = -4702.16 kJ/kg

Parameters in combustion chamber:

- Heat of isobaric combustion = -4593.78 kJ/kg
- Total enthalpy of combustion prod. = -4827.26 kJ/kg
- Entropy of combustion products = 10.41 kJ/K kg
- Isobaric combustion temperature = 2809.9 K
- Mole number of gaseous products = 39.030 mol/kg expl.
- Total mole number of products = 39.030 mol/kg expl.
- Volume of gaseous products (at SATP) = 967.51 L/kg expl.
- Mass of gaseous products = 1000.0 g/kg expl.
- Mass of condensed products = 0.0 g/kg expl.
- Mean molecular mass of gaseous prod. = 25.621 g
- Mean molecular mass of all products = 25.622 g
- Specific gas constant = 324.495 J/kg K
- Specific heat capacity at p=const. (Cp) = 2115.68 J/kgK
- Specific heat capacity at V=const. (Cv) = 1791.18 J/molK
- Specific heat ratio (Cp/Cv) = 1.1812

Composition of combustion products in chamber:

Products	mol/mol	mol/kg	Mol %
H2O =	1.233413 E00	2.373684 E01	60.8165
CO2 =	4.643984 E-01	8.937270 E00	22.8983
N2 =	1.472118 E-01	2.833067 E00	7.2586
CO =	6.224312 E-02	1.197859 E00	3.0690
O2 =	3.973797 E-02	7.647507 E-01	1.9594
OH =	3.239603 E-02	6.234562 E-01	1.5974
H2 =	2.215184 E-02	4.263085 E-01	1.0923
Fe(OH)2 =	1.415563 E-02	2.724227 E-01	0.6980
NO =	7.768570 E-03	1.495048 E-01	0.3830
H =	2.249929 E-03	4.329951 E-02	0.1109
O =	1.920136 E-03	3.695269 E-02	0.0947
FeO =	4.288980 E-04	8.254071 E-03	0.0211
FeO(s) =	1.477974 E-05	2.844337 E-04	0.0007
NH3 =	4.126840 E-07	7.942036 E-06	0.0000
N =	1.807182 E-07	3.477892 E-06	0.0000
NH2 =	1.240517 E-07	2.387354 E-06	0.0000
CHNO =	3.968749 E-08	7.637791 E-07	0.0000
HCN =	4.477660 E-09	8.617184 E-08	0.0000
CNO =	1.778796 E-09	3.423265 E-08	0.0000
Fe3O4(s) =	1.009479 E-11	1.942726 E-10	0.0000
N2H4 =	3.342013 E-15	6.431648 E-14	0.0000

Parameters at the nozzle throat:

- Total enthalpy of combustion prod. = -5330.04 kJ/kg
- Temperature at nozzle throat = 2647.9 K
- Pressure at nozzle throat = 4.0 MPa
- Mole number of gaseous products = 38.758 mol/kg expl.
- Total mole number of products = 38.804 mol/kg expl.
- Volume of gaseous products (at SATP) = 960.76 L/kg expl.
- Mass of gaseous products = 996.7 g/kg expl.
- Mass of condensed products = 3.3 g/kg expl.

- Mean molecular mass of gaseous prod. = 25.716 g
- Mean molecular mass of all products = 25.771 g
- Specific gas constant = 322.231 J/kg K
- Specific heat capacity at p=const. (Cp) = 2096.95 J/kgK
- Specific heat capacity at V=const. (Cv) = 1774.72 J/molK
- Specific heat ratio (Cp/Cv) = 1.1816

Characteristic parameters at the nozzle throat:

- Flow velocity at nozzle throat = 1002.8 m/s
- Sound velocity at throat) = 1004.1 m/s
- Mach number at nozzle throat = 0.999
- Critical pressure ratio (pt/pc) = 0.565
- Pressure ratio (pc/pt) = 1.770

Composition of combustion products at nozzle throat:

Products	mol/mol	mol/kg	Mol %
H2O =	1.245833 E00	2.397585 E01	61.7875
CO2 =	4.806776 E-01	9.250562 E00	23.8394
N2 =	1.483285 E-01	2.854558 E00	7.3564
CO =	4.596389 E-02	8.845676 E-01	2.2796
O2 =	3.252840 E-02	6.260037 E-01	1.6133
OH =	2.333183 E-02	4.490171 E-01	1.1572
H2 =	1.691361 E-02	3.254997 E-01	0.8388
Fe(OH)2 =	1.191684 E-02	2.293376 E-01	0.5910
NO =	5.535604 E-03	1.065318 E-01	0.2745
FeO(s) =	2.394181 E-03	4.607562 E-02	0.1187
H =	1.429953 E-03	2.751921 E-02	0.0709
O =	1.176429 E-03	2.264019 E-02	0.0583
FeO =	2.882887 E-04	5.548069 E-03	0.0143
NH3 =	1.805101 E-07	3.473886 E-06	0.0000
N =	6.803422 E-08	1.309307 E-06	0.0000
NH2 =	4.420628 E-08	8.507427 E-07	0.0000
CHNO =	1.407069 E-08	2.707882 E-07	0.0000
HCN =	1.240709 E-09	2.387723 E-08	0.0000
CNO =	4.734149 E-10	9.110791 E-09	0.0000
Fe3O4(s) =	4.142126 E-11	7.971452 E-10	0.0000
N2H4 =	5.200829 E-16	1.000891 E-14	0.0000

Parameters at the nozzle exit:

- Total enthalpy of combustion prod. = -7841.58 kJ/kg
- Temperature at nozzle exit = 1643.0 K
- Pressure at nozzle throat = 0.1 MPa
- Mole number of gaseous products = 37.962 mol/kg expl.
- Total mole number of products = 38.056 mol/kg expl.
- Volume of gaseous products (at SATP) = 941.05 L/kg expl.
- Mass of gaseous products = 978.4 g/kg expl.
- Mass of condensed products = 21.7 g/kg expl.
- Mean molecular mass of gaseous prod. = 25.772 g
- Mean molecular mass of all products = 26.278 g
- Specific gas constant = 315.619 J/kg K
- Specific heat capacity at p=const. (Cp) = 1901.14 J/kgK
- Specific heat capacity at V=const. (Cv) = 1585.52 J/molK
- Specific heat ratio (Cp/Cv) = 1.1991

Characteristic parameters at the nozzle exit:

- Specific impulse = 250.29 s
- Exhaust (or nozzle exit) velocity = 2455.3 m/s
- Characteristic exhaust velocity (c*) = 1452.5 m/s
- Thrust coefficient (Cf) = 1.690
- Nozzle area expansion ratio (Ae/At) = 9.08
- Pressure ratio (pc/pe) = 70.000
- Sound velocity at nozzle exit = 782.77 m/s
- Mach number at nozzle exit = 3.137

Composition of combustion products at the nozzle exit:

Products	mol/mol	mol/kg	Mol %
H2O =	1.286623 E00	2.476084 E01	65.0645
CO2 =	5.263994 E-01	1.013047 E01	26.6200
N2 =	1.509961 E-01	2.905895 E00	7.6359
O2 =	7.486129 E-03	1.440693 E-01	0.3786
Fe3O4(s) =	4.858925 E-03	9.350920 E-02	0.2457
OH =	4.487429 E-04	8.635983 E-03	0.0227
CO =	2.421732 E-04	4.660583 E-03	0.0122
NO =	2.007454 E-04	3.863311 E-03	0.0102
H2 =	1.742823 E-04	3.354034 E-03	0.0088
Fe(OH)2 =	2.252941 E-05	4.335748 E-04	0.0011
O =	2.907506 E-06	5.595448 E-05	0.0001
H =	1.648536 E-06	3.172581 E-05	0.0001
FeO =	3.928289 E-09	7.559927 E-08	0.0000
FeO(s) =	2.945487 E-11	5.668541 E-10	0.0000
NH3 =	2.899137 E-11	5.579341 E-10	0.0000
N =	6.893641 E-13	1.326670 E-11	0.0000
NH2 =	5.009930 E-13	9.641527 E-12	0.0000
CHNO =	1.816485 E-13	3.495795 E-12	0.0000
HCN =	2.793293 E-16	5.375647 E-15	0.0000
CNO =	2.058954 E-16	3.962423 E-15	0.0000
N2H4 =	3.270704 E-24	6.294417 E-23	0.0000

*Calculation for **F11** with H_2O_2 (95%)*

Combustion condition:

Isobaric combustion (p=const.)
Chamber pressure = 7.000 MPa
Ambient pressure = 0.100 MPa
Expansion conditions: Equilibrium expansion

Reactant information:

1. Water (H2O, liquid), 2.73%
2. Hydrogen peroxide (H2O2), 51.82 %
3. NCH4, 38.64%
4. JN-15, 6.81%

C(0.620) H(2.655) N(0.326) O(2.563) Fe(0.011)

Molecular weight = 56.29
Oxygen balance = -0.5541512%
Enthalpy of formation = -4880.13 kJ/kg
Internal energy of formation = -4758.07 kJ/kg

Parameters in combustion chamber:

- Heat of isobaric combustion = -4530.73 kJ/kg
- Total enthalpy of combustion prod. = -4880.97 kJ/kg
- Entropy of combustion products = 10.28 kJ/K kg
- Isobaric combustion temperature = 2807.7 K
- Mole number of gaseous products = 38.491 mol/kg expl.
- Total mole number of products = 38.493 mol/kg expl.
- Volume of gaseous products (at SATP) = 954.16 L/kg expl.
- Mass of gaseous products = 999.9 g/kg expl.
- Mass of condensed products = 0.1 g/kg expl.
- Mean molecular mass of gaseous prod. = 25.978 g
- Mean molecular mass of all products = 25.980 g
- Specific gas constant = 320.017 J/kg K
- Specific heat capacity at p=const. (Cp) = 2085.14 J/kgK
- Specific heat capacity at V=const. (Cv) = 1765.12 J/molK
- Specific heat ratio (Cp/Cv) = 1.1813

Composition of combustion products in chamber:

Products	mol/mol	mol/kg	Mol %
H2O =	1.274254 E00	2.263850 E01	58.8126
CO2 =	5.393078 E-01	9.581389 E00	24.8915
N2 =	1.591004 E-01	2.826592 E00	7.3432
CO =	8.027277 E-02	1.426133 E00	3.7050
O2 =	3.380027 E-02	6.004986 E-01	1.5600
OH =	3.198158 E-02	5.681875 E-01	1.4761
H2 =	2.543308 E-02	4.518463 E-01	1.1739
Fe(OH)2 =	1.037589 E-02	1.843389 E-01	0.4789
NO =	7.425881 E-03	1.319288 E-01	0.3427
H =	2.472825 E-03	4.393243 E-02	0.1141
O =	1.814935 E-03	3.224429 E-02	0.0838
FeO =	3.218885 E-04	5.718698 E-03	0.0149
FeO(s) =	7.187521 E-05	1.276941 E-03	0.0033
NH3 =	4.962134 E-07	8.815770 E-06	0.0000
N =	1.911048 E-07	3.395184 E-06	0.0000
NH2 =	1.423845 E-07	2.529614 E-06	0.0000
CHNO =	5.361103 E-08	9.524582 E-07	0.0000
HCN =	6.695436 E-09	1.189517 E-07	0.0000
CNO =	2.286903 E-09	4.062931 E-08	0.0000

Parameters at the nozzle throat:

- Total enthalpy of combustion prod. = -5377.33 kJ/kg
- Temperature at nozzle throat = 2644.3 K
- Pressure at nozzle throat = 4.0 MPa
- Mole number of gaseous products = 38.214 mol/kg expl.
- Total mole number of products = 38.214 mol/kg expl.
- Volume of gaseous products (at SATP) = 947.28 L/kg expl.
- Mass of gaseous products = 1000.0 g/kg expl.
- Mass of condensed products = 0.0 g/kg expl.
- Mean molecular mass of gaseous prod. = 26.169 g
- Mean molecular mass of all products = 26.169 g
- Specific gas constant = 317.708 J/kg K
- Specific heat capacity at p=const. (Cp) = 2065.93 J/kgK
- Specific heat capacity at V=const. (Cv) = 1748.22 J/molK
- Specific heat ratio (Cp/Cv) = 1.1817

Characteristic parameters at the nozzle throat:

- Flow velocity at nozzle throat = 996.4 m/s
- Sound velocity at throat) = 996.4 m/s
- Mach number at nozzle throat = 1.000
- Critical pressure ratio (pt/pc) = 0.565
- Pressure ratio (pc/pt) = 1.770

Composition of combustion products at nozzle throat:

Products	mol/mol	mol/kg	Mol %
H2O =	1.284706 E00	2.282420 E01	59.7278
CO2 =	5.582204 E-01	9.917393 E00	25.9525
N2 =	1.602857 E-01	2.847649 E00	7.4519
CO =	6.136020 E-02	1.090131 E00	2.8527
O2 =	2.540030 E-02	4.512638 E-01	1.1809
OH =	2.241344 E-02	3.981992 E-01	1.0420
H2 =	2.007731 E-02	3.566952 E-01	0.9334
Fe(OH)2 =	1.050679 E-02	1.866645 E-01	0.4885
NO =	5.055880 E-03	8.982320 E-02	0.2351
H =	1.587122 E-03	2.819694 E-02	0.0738
O =	1.057213 E-03	1.878253 E-02	0.0492
FeO =	2.583553 E-04	4.589962 E-03	0.0120
FeO(s) =	4.507595 E-06	8.008232 E-05	0.0002
NH3 =	2.280512 E-07	4.051577 E-06	0.0000
N =	7.092853 E-08	1.260122 E-06	0.0000
NH2 =	5.219519 E-08	9.273043 E-07	0.0000
CHNO =	1.990752 E-08	3.536787 E-07	0.0000
HCN =	2.022572 E-09	3.593319 E-08	0.0000
CNO =	6.248091 E-10	1.110041 E-08	0.0000

Parameters at the nozzle exit:

- Total enthalpy of combustion prod. = -7842.11 kJ/kg
- Temperature at nozzle exit = 1625.1 K
- Pressure at nozzle throat = 0.1 MPa
- Mole number of gaseous products = 37.482 mol/kg expl.
- Total mole number of products = 37.672 mol/kg expl.
- Volume of gaseous products (at SATP) = 929.13 L/kg expl.
- Mass of gaseous products = 986.4 g/kg expl.
- Mass of condensed products = 13.7 g/kg expl.
- Mean molecular mass of gaseous prod. = 26.316 g
- Mean molecular mass of all products = 26.546 g
- Specific gas constant = 311.623 J/kg K
- Specific heat capacity at p=const. (Cp) = 1871.32 J/kgK
- Specific heat capacity at V=const. (Cv) = 1559.70 J/molK
- Specific heat ratio (Cp/Cv) = 1.1998

Characteristic parameters at the nozzle exit:

- Specific impulse = 248.07 s
- Exhaust (or nozzle exit) velocity = 2433.6 m/s
- Characteristic exhaust velocity (c*) = 1442.4 m/s
- Thrust coefficient (Cf) = 1.687
- Nozzle area expansion ratio (Ae/At) = 9.07
- Pressure ratio (pc/pe) = 70.000
- Sound velocity at nozzle exit = 773.59 m/s
- Mach number at nozzle exit = 3.146

Composition of combustion products at the nozzle exit:

Products	mol/mol	mol/kg	Mol %
H2O =	1.321590 E00	2.347948 E01	62.3266
CO2 =	6.110108 E-01	1.085527 E01	28.8155
N2 =	1.628107 E-01	2.892509 E00	7.6782
FeO(s) =	1.069545 E-02	1.900163 E-01	0.5044
CO =	8.569854 E-03	1.522528 E-01	0.4042
H2 =	5.589135 E-03	9.929705 E-02	0.2636
Fe(OH)2 =	7.419241 E-05	1.318109 E-03	0.0035
OH =	6.677073 E-05	1.186255 E-03	0.0031
H =	8.156158 E-06	1.449030 E-04	0.0004
O2 =	6.174186 E-06	1.096911 E-04	0.0003
NO =	6.173574 E-06	1.096802 E-04	0.0003
O =	7.630486 E-08	1.355639 E-06	0.0000
FeO =	1.046496 E-08	1.859213 E-07	0.0000
NH3 =	4.008073 E-09	7.120778 E-08	0.0000
CHNO =	2.051928 E-11	3.645473 E-10	0.0000
NH2 =	1.255047 E-11	2.229728 E-10	0.0000
HCN =	1.182432 E-12	2.100719 E-11	0.0000
N =	3.164827 E-13	5.622659 E-12	0.0000
CNO =	3.375909 E-15	5.997669 E-14	0.0000

*Calculation for **F4** with O_2 (liquid)*

Combustion condition:

Isobaric combustion (p=const.)
Chamber pressure = 7.000 MPa
Ambient pressure = 0.100 MPa
Expansion conditions: Equilibrium expansion

Reactant information:

1. NCH4, 56.67%
2. Oxygen (O2, liquid), 33.33%
3. Mn-Gu, 10 %

C(1.260) H(1.576) N(0.672) O(3.471) Mn(0.020)

Molecular weight = 82.78
Oxygen balance = 2.76138%
Enthalpy of formation = -3044.15 kJ/kg
Internal energy of formation = -2958.52 kJ/kg

Parameters in combustion chamber:

- Heat of isobaric combustion = -4196.16 kJ/kg
- Total enthalpy of combustion prod. = -3044.36 kJ/kg
- Entropy of combustion products = 8.88 kJ/K kg
- Isobaric combustion temperature = 3119.2 K
- Mole number of gaseous products = 31.630 mol/kg expl.
- Total mole number of products = 31.875 mol/kg expl.
- Volume of gaseous products (at SATP) = 784.09 L/kg expl.
- Mass of gaseous products = 982.7 g/kg expl.
- Mass of condensed products = 17.3 g/kg expl.
- Mean molecular mass of gaseous prod. = 31.068 g
- Mean molecular mass of all products = 31.373 g
- Specific gas constant = 262.975 J/kg K
- Specific heat capacity at p=const. (Cp) = 1676.02 J/kgK
- Specific heat capacity at V=const. (Cv) = 1413.05 J/molK
- Specific heat ratio (Cp/Cv) = 1.1861

Composition of combustion products in chamber:

Products	mol/mol	mol/kg	Mol %
CO2 =	1.016088 E00	1.227459 E01	38.5088
H2O =	7.257499 E-01	8.767235 E00	27.5053
N2 =	3.190043 E-01	3.853650 E00	12.0900
CO =	2.438256 E-01	2.945472 E00	9.2408
O2 =	1.632384 E-01	1.971960 E00	6.1866
OH =	7.492659 E-02	9.051315 E-01	2.8397
NO =	3.432924 E-02	4.147055 E-01	1.3010
H2 =	2.138385 E-02	2.583221 E-01	0.8104
MnO(s) =	2.022833 E-02	2.443632 E-01	0.7666
O =	1.314673 E-02	1.588157 E-01	0.4982
H =	6.659803 E-03	8.045203 E-02	0.2524
N =	2.343463 E-06	2.830960 E-05	0.0001
NH3 =	3.606196 E-07	4.356372 E-06	0.0000
NH2 =	3.400880 E-07	4.108346 E-06	0.0000
CHNO =	1.889731 E-07	2.282841 E-06	0.0000
HCN =	3.265534 E-08	3.944844 E-07	0.0000
CNO =	3.020193 E-08	3.648466 E-07	0.0000
MnC2(s) =	2.730088 E-12	3.298013 E-11	0.0000
MnO2(s) =	1.733050 E-13	2.093566 E-12	0.0000
MnO(l) =	3.424721 E-17	4.137146 E-16	0.0000

Parameters at the nozzle throat:

- Total enthalpy of combustion prod. = -3501.15 kJ/kg
- Temperature at nozzle throat = 2964.0 K
- Pressure at nozzle throat = 3.9 MPa
- Mole number of gaseous products = 31.287 mol/kg expl.
- Total mole number of products = 31.531 mol/kg expl.
- Volume of gaseous products (at SATP) = 775.56 L/kg expl.
- Mass of gaseous products = 982.7 g/kg expl.
- Mass of condensed products = 17.3 g/kg expl.
- Mean molecular mass of gaseous prod. = 31.409 g
- Mean molecular mass of all products = 31.716 g
- Specific gas constant = 260.117 J/kg K
- Specific heat capacity at p=const. (Cp) = 1667.85 J/kgK

- Specific heat capacity at V=const. (Cv) = 1407.74 J/molK
- Specific heat ratio (Cp/Cv) = 1.1848

Characteristic parameters at the nozzle throat:

- Flow velocity at nozzle throat = 955.8 m/s
- Sound velocity at throat) = 955.7 m/s
- Mach number at nozzle throat = 1.000
- Critical pressure ratio (pt/pc) = 0.563
- Pressure ratio (pc/pt) = 1.775

Composition of combustion products at nozzle throat:

Products	mol/mol	mol/kg	Mol %
CO2 =	1.057277 E00	1.277216 E01	40.5068
H2O =	7.366788 E-01	8.899259 E00	28.2239
N2 =	3.224868 E-01	3.895720 E00	12.3552
CO =	2.026363 E-01	2.447896 E00	7.7635
O2 =	1.490942 E-01	1.801094 E00	5.7121
OH =	6.129449 E-02	7.404523 E-01	2.3483
NO =	2.736584 E-02	3.305860 E-01	1.0484
MnO(s) =	2.022833 E-02	2.443632 E-01	0.7750
H2 =	1.805314 E-02	2.180863 E-01	0.6917
O =	9.912307 E-03	1.197431 E-01	0.3798
H =	5.096515 E-03	6.156714 E-02	0.1953
N =	1.177725 E-06	1.422720 E-05	0.0000
NH3 =	1.774358 E-07	2.143467 E-06	0.0000
NH2 =	1.499562 E-07	1.811508 E-06	0.0000
CHNO =	7.958258 E-08	9.613769 E-07	0.0000
HCN =	1.180653 E-08	1.426257 E-07	0.0000
CNO =	1.072050 E-08	1.295062 E-07	0.0000
MnC2(s) =	1.122079 E-12	1.355499 E-11	0.0000
MnO2(s) =	1.608630 E-13	1.943264 E-12	0.0000
MnO(l) =	4.579006 E-17	5.531550 E-16	0.0000

Parameters at the nozzle exit:

- Total enthalpy of combustion prod. = -5836.47 kJ/kg
- Temperature at nozzle exit = 2058.0 K
- Pressure at nozzle throat = 0.1 MPa
- Mole number of gaseous products = 29.789 mol/kg expl.
- Total mole number of products = 30.033 mol/kg expl.
- Volume of gaseous products (at SATP) = 738.44 L/kg expl.
- Mass of gaseous products = 982.7 g/kg expl.
- Mass of condensed products = 17.3 g/kg expl.
- Mean molecular mass of gaseous prod. = 32.988 g
- Mean molecular mass of all products = 33.297 g
- Specific gas constant = 247.666 J/kg K
- Specific heat capacity at p=const. (Cp) = 1583.04 J/kgK
- Specific heat capacity at V=const. (Cv) = 1335.38 J/molK
- Specific heat ratio (Cp/Cv) = 1.1855

Characteristic parameters at the nozzle exit:

- Specific impulse = 240.89 s
- Exhaust (or nozzle exit) velocity = 2363.1 m/s
- Characteristic exhaust velocity (c*) = 1361.2 m/s

- Thrust coefficient (Cf) = 1.736
- Nozzle area expansion ratio (Ae/At) = 9.33
- Pressure ratio (pc/pe) = 70.000
- Sound velocity at nozzle exit = 777.10 m/s
- Mach number at nozzle exit = 3.041

Composition of combustion products at the nozzle exit:

Products	mol/mol	mol/kg	Mol %
CO2 =	1.245118 E00	1.504133 E01	50.0821
H2O =	7.823856 E-01	9.451408 E00	31.4697
N2 =	3.342702 E-01	4.038065 E00	13.4453
O2 =	7.584195 E-02	9.161892 E-01	3.0506
MnO(s) =	2.022833 E-02	2.443632 E-01	0.8136
CO =	1.479549 E-02	1.787331 E-01	0.5951
OH =	7.281952 E-03	8.796775 E-02	0.2929
NO =	3.800814 E-03	4.591476 E-02	0.1529
H2 =	1.817454 E-03	2.195529 E-02	0.0731
O =	4.466028 E-04	5.395070 E-03	0.0180
H =	1.677248 E-04	2.026157 E-03	0.0067
N =	1.360026 E-09	1.642944 E-08	0.0000
NH3 =	3.972258 E-10	4.798585 E-09	0.0000
NH2 =	9.352206 E-11	1.129769 E-09	0.0000
CHNO =	3.845316 E-11	4.645236 E-10	0.0000
CNO =	8.509405 E-13	1.027957 E-11	0.0000
HCN =	6.963577 E-13	8.412171 E-12	0.0000
MnO2(s) =	1.628615 E-13	1.967407 E-12	0.0000
MnC2(s) =	1.277198 E-16	1.542887 E-15	0.0000
MnO(l) =	2.224263 E-17	2.686963 E-16	0.0000

*Calculation for **F10** with O_2 (liquid)*

Combustion condition:

Isobaric combustion (p=const.)
Chamber pressure = 7.000 MPa
Ambient pressure = 0.100 MPa
Expansion conditions: Equilibrium expansion

Reactant information:

1. NCH4, 46.87 %
2. JN-15, 15.63 %
3. Oxygen (O2, liquid), 37.5 %

C(1.218) H(1.525) N(0.699) O(3.067) Fe(0.034)

Molecular weight = 76.9
Oxygen balance = -3.7941 %
Enthalpy of formation = -2048.27 kJ/kg
Internal energy of formation = -1963.01 kJ/kg

Parameters in combustion chamber:

- Heat of isobaric combustion = -4524.15 kJ/kg
- Total enthalpy of combustion prod. = -2048.76 kJ/kg
- Entropy of combustion products = 9.22 kJ/K kg
- Isobaric combustion temperature = 3312.8 K
- Mole number of gaseous products = 33.020 mol/kg expl.
- Total mole number of products = 33.176 mol/kg expl.
- Volume of gaseous products (at SATP) = 818.53 L/kg expl.
- Mass of gaseous products = 988.8 g/kg expl.
- Mass of condensed products = 11.2 g/kg expl.
- Mean molecular mass of gaseous prod. = 29.946 g
- Mean molecular mass of all products = 30.143 g
- Specific gas constant = 274.528 J/kg K
- Specific heat capacity at p=const. (Cp) = 1681.89 J/kgK
- Specific heat capacity at V=const. (Cv) = 1407.36 J/molK
- Specific heat ratio (Cp/Cv) = 1.1951

Composition of combustion products in chamber:

Products	mol/mol	mol/kg	Mol %
CO2 =	7.925963 E-01	1.030643 E01	31.0659
H2O =	6.572938 E-01	8.547040 E00	25.7627
CO =	4.252940 E-01	5.530258 E00	16.6694
N2 =	3.319019 E-01	4.315846 E00	13.0089
O2 =	1.079677 E-01	1.403945 E00	4.2318
OH =	9.180199 E-02	1.193736 E00	3.5982
H2 =	4.149847 E-02	5.396203 E-01	1.6265
NO =	3.507120 E-02	4.560441 E-01	1.3746
O =	1.878445 E-02	2.442614 E-01	0.7363
H =	1.535094 E-02	1.996141 E-01	0.6017
FeO(l) =	1.200480 E-02	1.561029 E-01	0.4705
Fe(OH)2 =	1.018812 E-02	1.324800 E-01	0.3993
Fe =	6.707346 E-03	8.721816 E-02	0.2629
FeO =	4.871144 E-03	6.334133 E-02	0.1909
N =	6.993219 E-06	9.093548 E-05	0.0003
NH2 =	1.040200 E-06	1.352611 E-05	0.0000
NH3 =	9.187906 E-07	1.194738 E-05	0.0000
CHNO =	5.048768 E-07	6.565105 E-06	0.0000
HCN =	1.812337 E-07	2.356651 E-06	0.0000
CNO =	1.041959 E-07	1.354899 E-06	0.0000
FeO(s) =	1.304943 E-09	1.696866 E-08	0.0000
Fe(l) =	3.806205 E-12	4.949352 E-11	0.0000
Fe(s) =	1.491691 E-12	1.939702 E-11	0.0000

Parameters at the nozzle throat:

- Total enthalpy of combustion prod. = -2558.09 kJ/kg
- Temperature at nozzle throat = 3152.5 K
- Pressure at nozzle throat = 3.9 MPa
- Mole number of gaseous products = 32.595 mol/kg expl.
- Total mole number of products = 32.801 mol/kg expl.
- Volume of gaseous products (at SATP) = 808.00 L/kg expl.
- Mass of gaseous products = 985.3 g/kg expl.
- Mass of condensed products = 14.8 g/kg expl.
- Mean molecular mass of gaseous prod. = 30.227 g
- Mean molecular mass of all products = 30.488 g
- Specific gas constant = 270.997 J/kg K
- Specific heat capacity at p=const. (Cp) = 1676.77 J/kgK
- Specific heat capacity at V=const. (Cv) = 1405.77 J/molK
- Specific heat ratio (Cp/Cv) = 1.1928

Characteristic parameters at the nozzle throat:

- Flow velocity at nozzle throat = 1009.3 m/s
- Sound velocity at throat) = 1009.5 m/s
- Mach number at nozzle throat = 1.000
- Critical pressure ratio (pt/pc) = 0.561
- Pressure ratio (pc/pt) = 1.782

Composition of combustion products at nozzle throat:

Products	mol/mol	mol/kg	Mol %
CO2 =	8.334028 E-01	1.083705 E01	33.0392
H2O =	6.717935 E-01	8.735585 E00	26.6324
CO =	3.844880 E-01	4.999643 E00	15.2426
N2 =	3.355611 E-01	4.363428 E00	13.3029
O2 =	9.409191 E-02	1.223513 E00	3.7302
OH =	7.666931 E-02	9.969600 E-01	3.0395
H2 =	3.775498 E-02	4.909424 E-01	1.4967
NO =	2.775749 E-02	3.609412 E-01	1.1004
FeO(l) =	1.579089 E-02	2.053350 E-01	0.6260
O =	1.447549 E-02	1.882302 E-01	0.5739
H =	1.269488 E-02	1.650763 E-01	0.5033
Fe(OH)2 =	8.327660 E-03	1.082877 E-01	0.3301
Fe =	5.646089 E-03	7.341824 E-02	0.2238
FeO =	4.006763 E-03	5.210146 E-02	0.1588
N =	3.822519 E-06	4.970566 E-05	0.0002
NH2 =	5.090207 E-07	6.618988 E-06	0.0000
NH3 =	4.989870 E-07	6.488518 E-06	0.0000
CHNO =	2.399186 E-07	3.119752 E-06	0.0000
HCN =	7.877837 E-08	1.024385 E-06	0.0000
CNO =	4.208824 E-08	5.472893 E-07	0.0000
FeO(s) =	7.040583 E-11	9.155137 E-10	0.0000

Fe(l) =	3.449794 E-12	4.485898 E-11	0.0000
Fe(s) =	1.547225 E-12	2.011915 E-11	0.0000

Parameters at the nozzle exit:

- Total enthalpy of combustion prod. = -5162.44 kJ/kg
- Temperature at nozzle exit = 2280.8 K
- Pressure at nozzle throat = 0.1 MPa
- Mole number of gaseous products = 30.530 mol/kg expl.
- Total mole number of products = 30.943 mol/kg expl.
- Volume of gaseous products (at SATP) = 756.80 L/kg expl.
- Mass of gaseous products = 970.3 g/kg expl.
- Mass of condensed products = 29.7 g/kg expl.
- Mean molecular mass of gaseous prod. = 31.783 g
- Mean molecular mass of all products = 32.318 g
- Specific gas constant = 253.824 J/kg K
- Specific heat capacity at p=const. (Cp) = 1618.65 J/kgK
- Specific heat capacity at V=const. (Cv) = 1364.82 J/molK
- Specific heat ratio (Cp/Cv) = 1.1860

Characteristic parameters at the nozzle exit:

- Specific impulse = 254.38 s
- Exhaust (or nozzle exit) velocity = 2495.5 m/s
- Characteristic exhaust velocity (c*) = 1419.9 m/s
- Thrust coefficient (Cf) = 1.757
- Nozzle area expansion ratio (Ae/At) = 9.32
- Pressure ratio (pc/pe) = 70.000
- Sound velocity at nozzle exit = 830.97 m/s
- Mach number at nozzle exit = 3.003

Composition of combustion products at the nozzle exit:

Products	mol/mol	mol/kg	Mol %
CO2 =	1.047645 E00	1.362292 E01	44.0255
H2O =	7.349986 E-01	9.557466 E00	30.8871
N2 =	3.482984 E-01	4.529057 E00	14.6367
CO =	1.702461 E-01	2.213774 E00	7.1543
FeO(l) =	3.166860 E-02	4.117987 E-01	1.3308
H2 =	2.017670 E-02	2.623653 E-01	0.8479
OH =	1.039061 E-02	1.351131 E-01	0.4366
O2 =	9.165977 E-03	1.191887 E-01	0.3852
NO =	2.287939 E-03	2.975094 E-02	0.0961
H =	1.997049 E-03	2.596838 E-02	0.0839
Fe(OH)2 =	1.190391 E-03	1.547911 E-02	0.0500
O =	6.519326 E-04	8.477326 E-03	0.0274
Fe =	5.326706 E-04	6.926518 E-03	0.0224
FeO =	2.483884 E-04	3.229889 E-03	0.0104

FeO(s) =	1.313592 E-04	1.708113 E-03	0.0055
N =	2.100792 E-08	2.731740 E-07	0.0000
NH3 =	1.153660 E-08	1.500147 E-07	0.0000
NH2 =	3.099557 E-09	4.030472 E-08	0.0000
CHNO =	1.699721 E-09	2.210212 E-08	0.0000
HCN =	3.362174 E-10	4.371962 E-09	0.0000
CNO =	5.052957 E-11	6.570551 E-10	0.0000
Fe(l) =	1.631571 E-12	2.121594 E-11	0.0000
Fe(s) =	1.312016 E-12	1.706064 E-11	0.0000

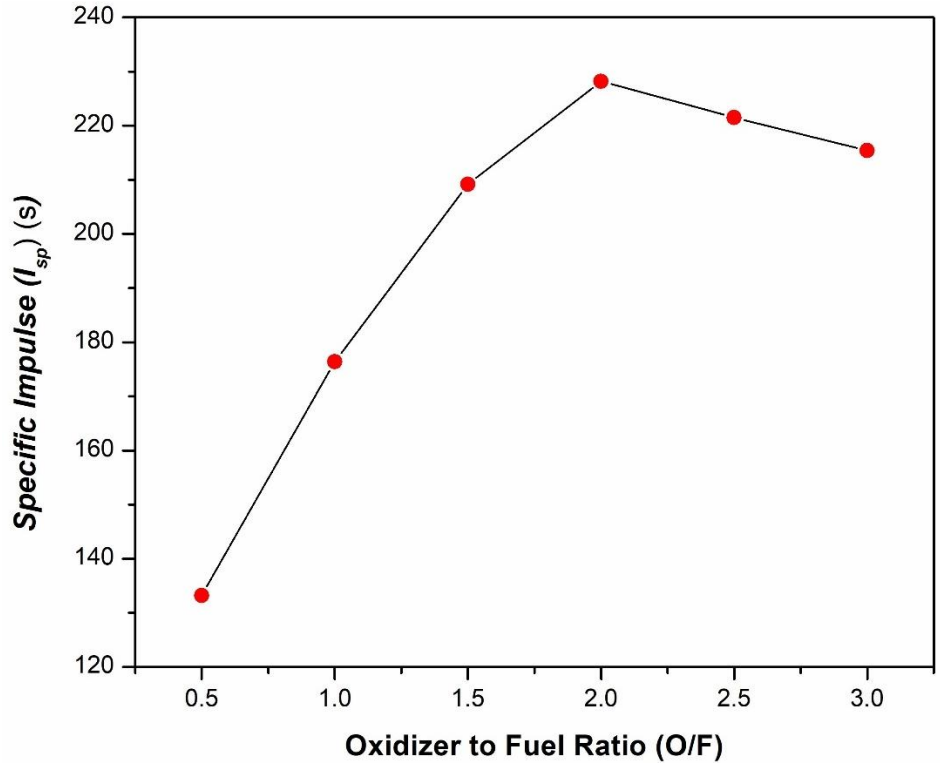

Figure S27. Specific impulse of **Mn-GU** with H_2O_2 (95%)

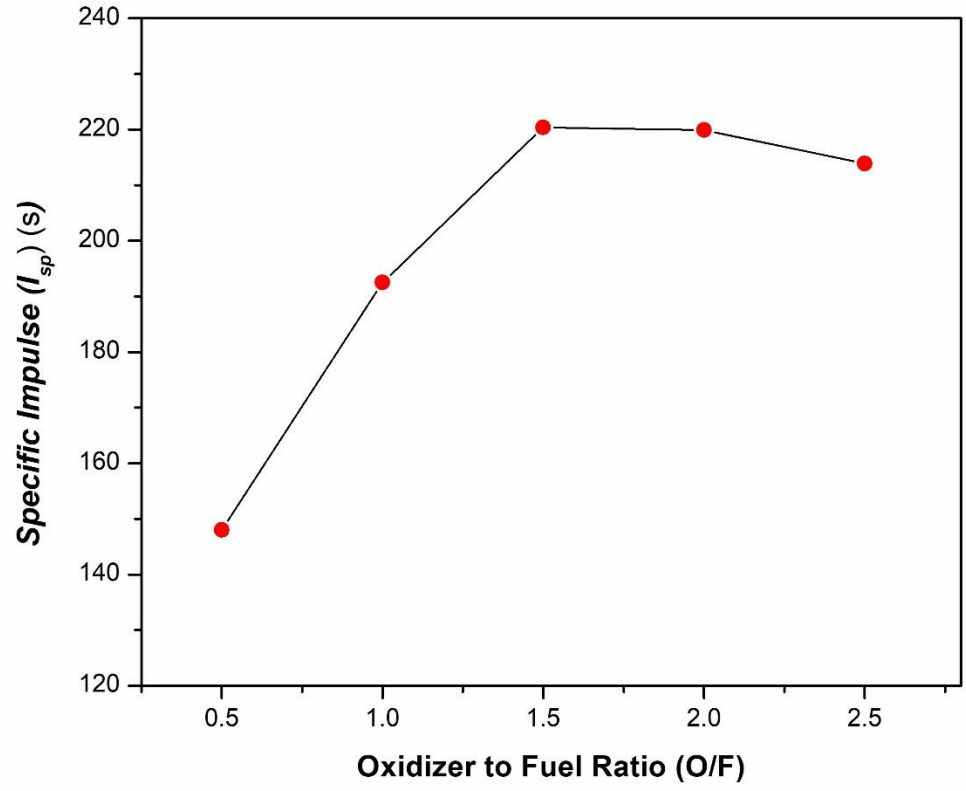

Figure S28. Specific impulse of **Cu-GU** with H_2O_2 (95%)

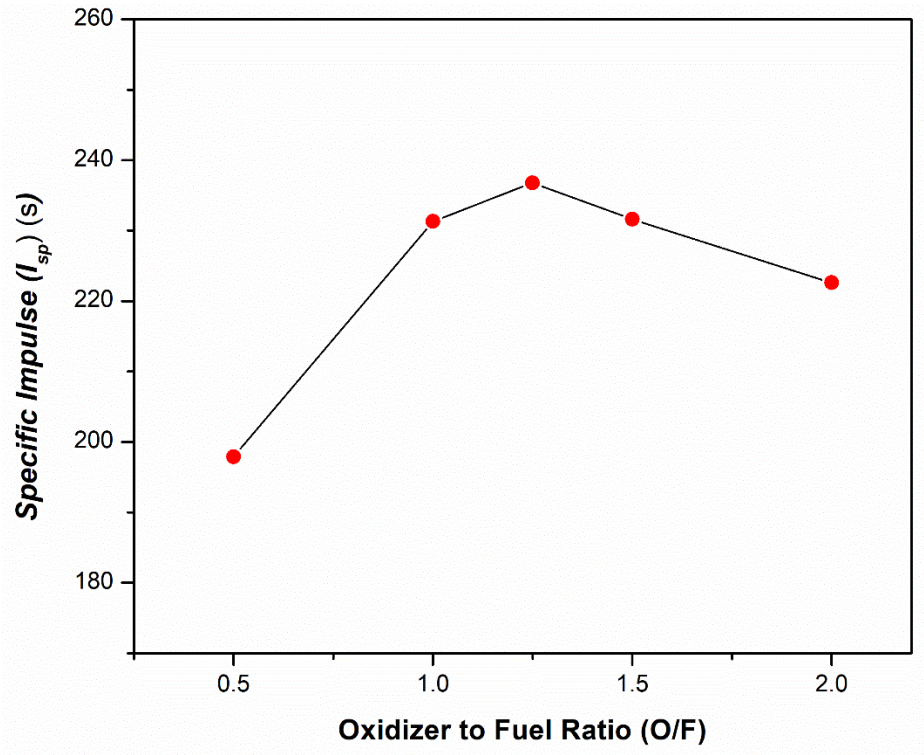

Figure S29. Specific impulse of formulation **F1** with H_2O_2 (95%)

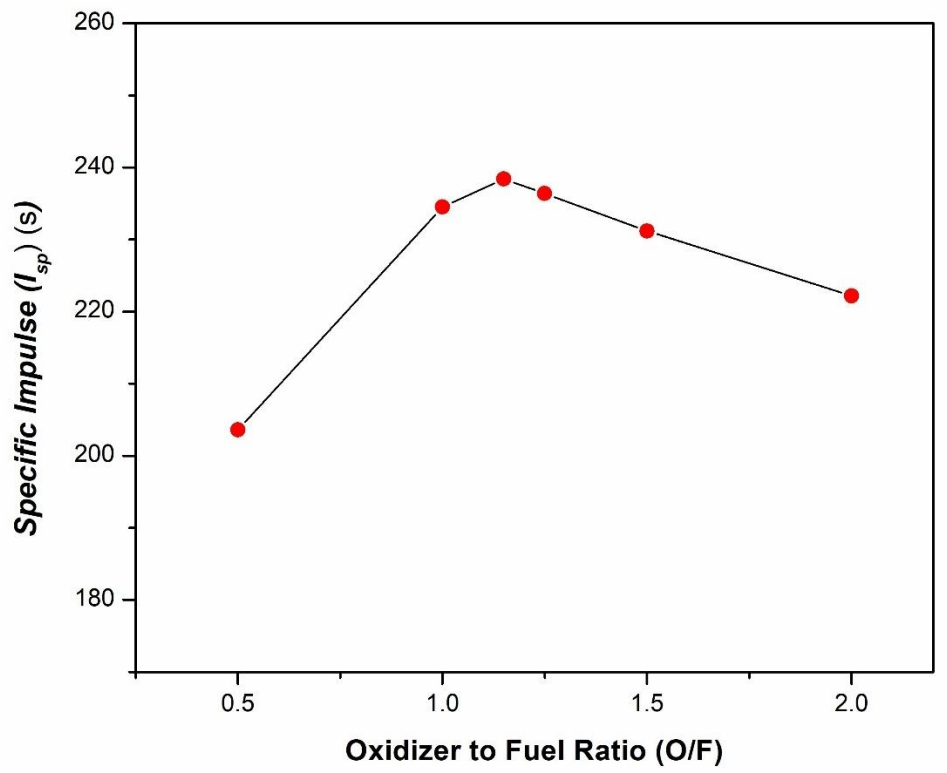

Figure S30. Specific impulse of formulation **F2** with H_2O_2 (95%)

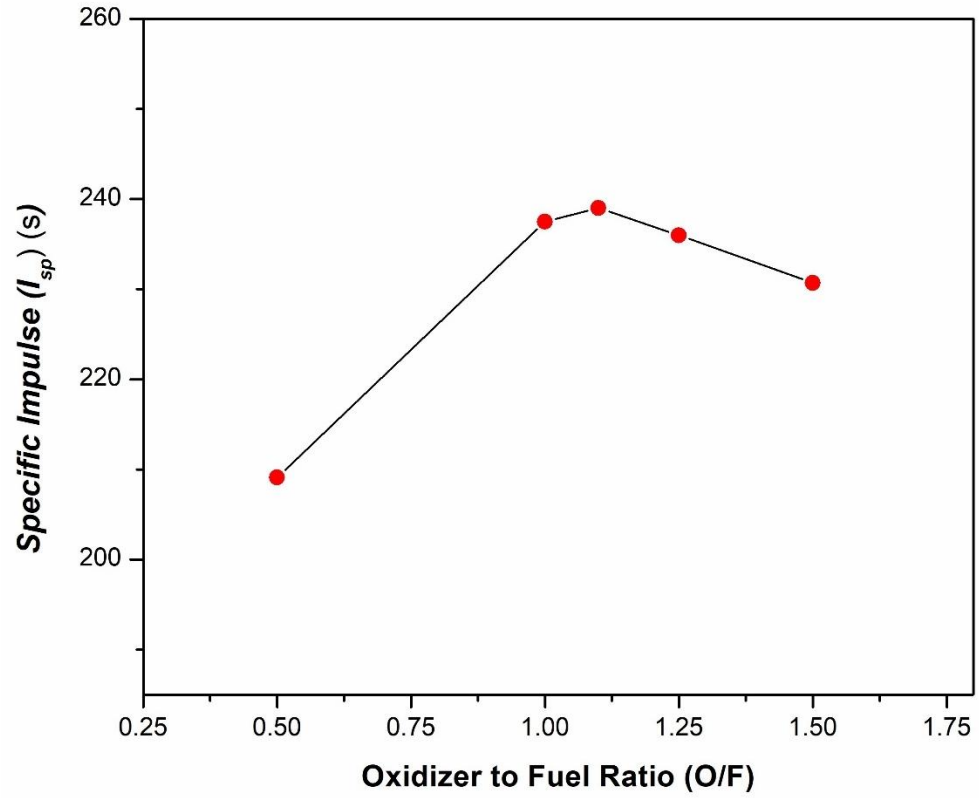

Figure S31. Specific impulse of formulation **F3** with H_2O_2 (95%)

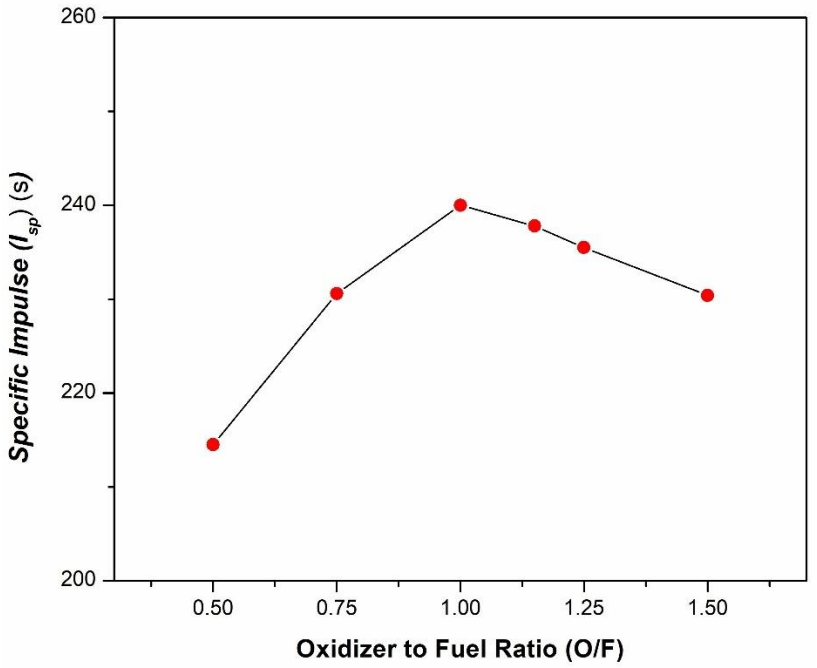

Figure S32. Specific impulse of formulation **F4** with H_2O_2 (95%)

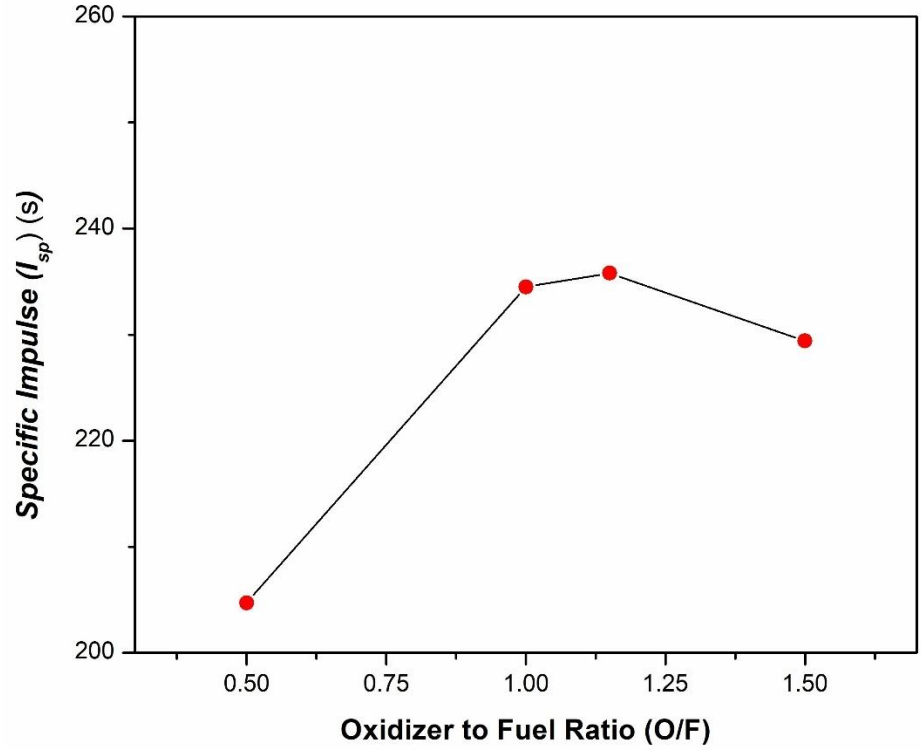

Figure S33. Specific impulse of formulation **F8** with H_2O_2 (95%)

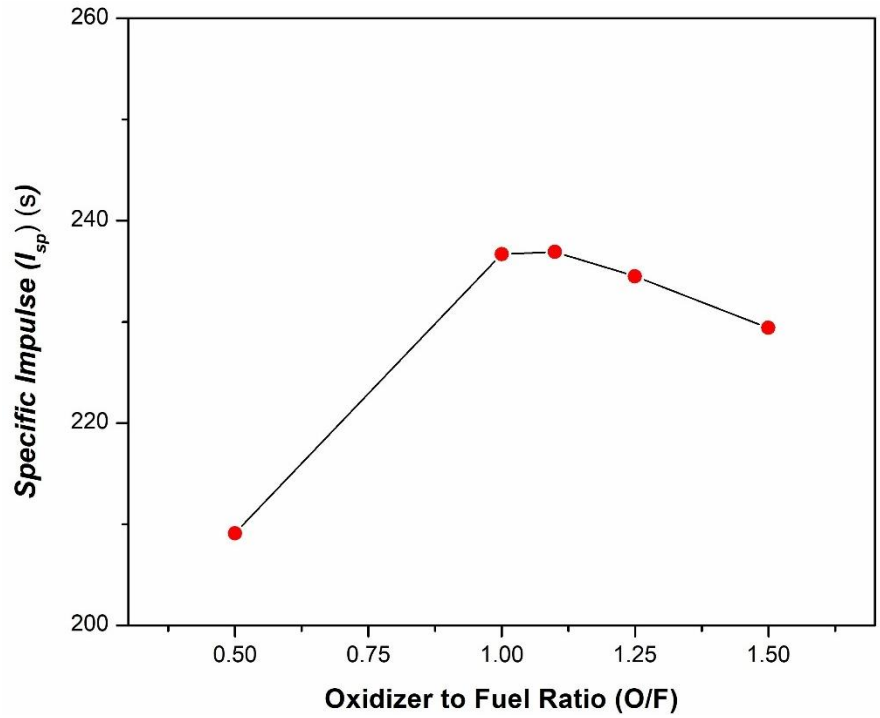

Figure S34. Specific impulse of formulation **F9** with H_2O_2 (95%)

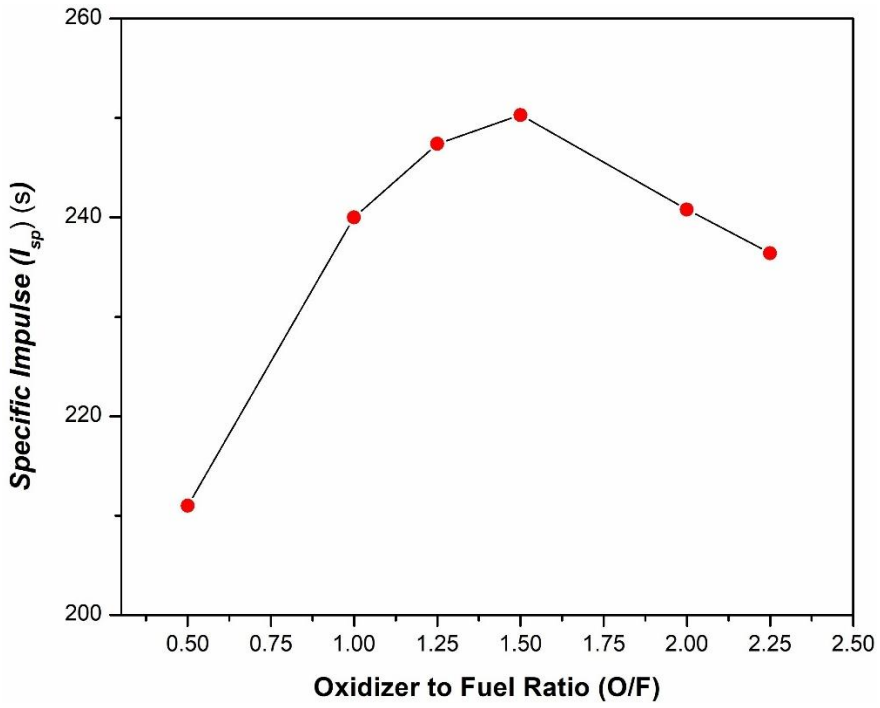

Figure S35. Specific impulse of formulation **F10** with H_2O_2 (95%)

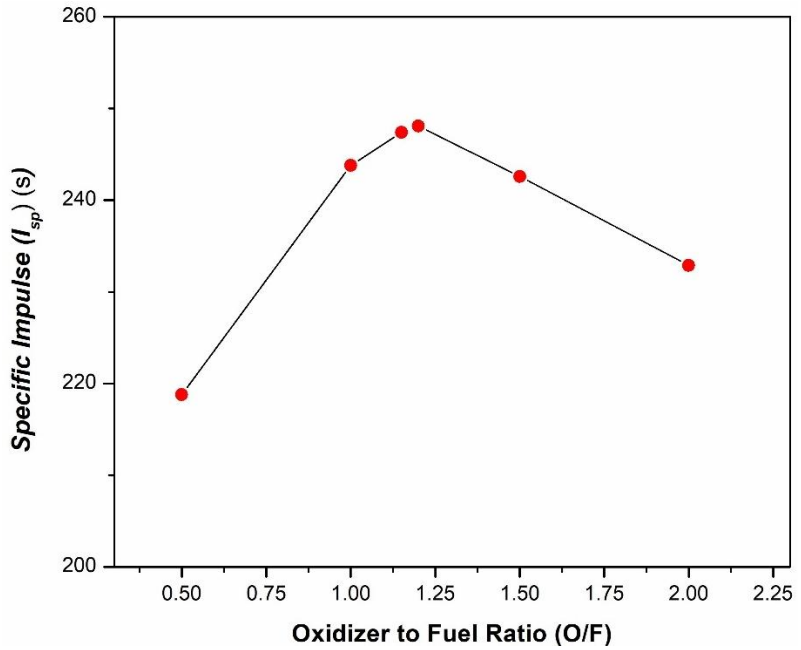

Figure S36. Specific impulse of formulation **F11** with H_2O_2 (95%)

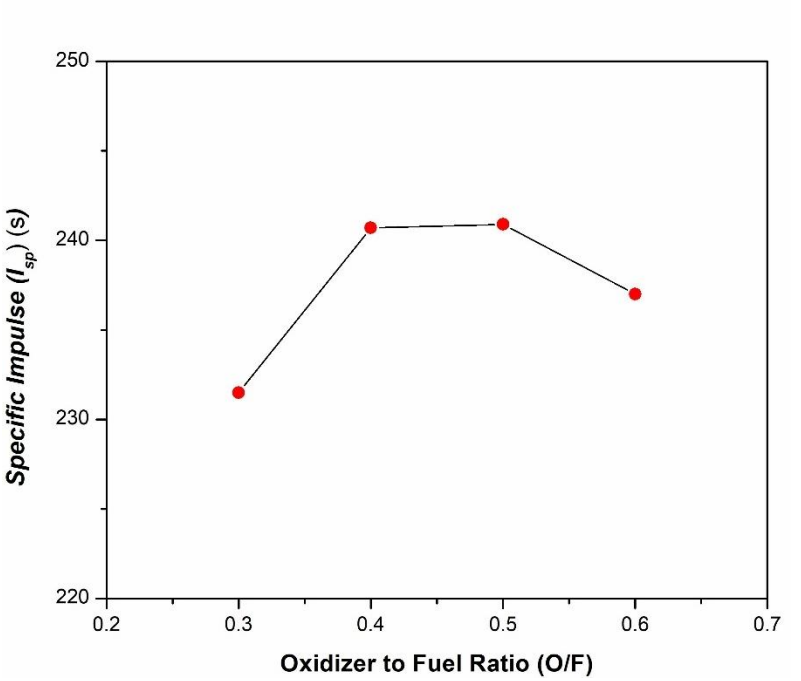

Figure S37. Specific impulse of formulation **F4** with liquid O_2

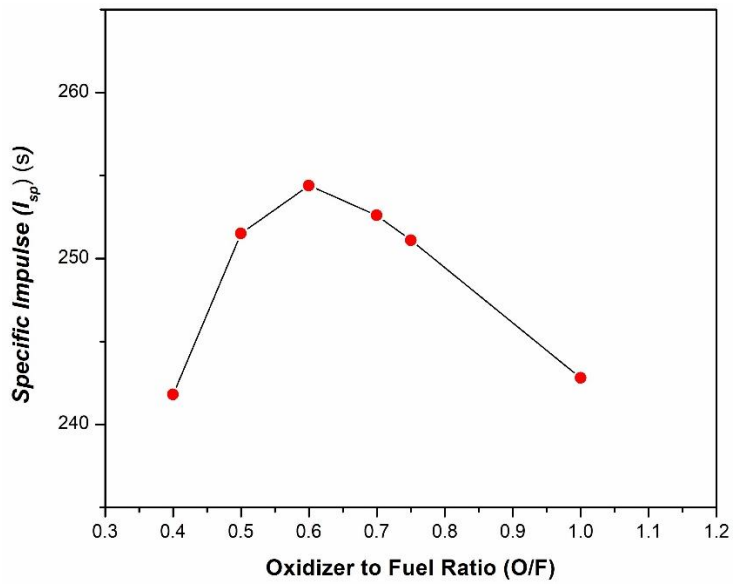

Figure S38. Specific impulse of formulation **F10** with liquid O_2

Density Specific Impulse Calculation

Density of **Mn-Gu** = 1.80 g·cm^{-3}
Density of **Cu-Gu** = 1.74 g·cm^{-3}
Density of **NCH4** = 1.38 g·cm^{-3}
Density of **JN-15** = 1.52 g·cm^{-3}
Density of H_2O_2 (95%) = 1.41 g·cm^{-3}
Density of **F1** = 1 / {(0.3/1.8) + (0.7/1.38)} = 1.48 g·cm^{-3}
Density of **F2** = 1 / {(0.25/1.8) + (0.75/1.38)} = 1.47 g·cm^{-3}
Density of **F3** = 1 / {(0.2/1.8) + (0.8/1.38)} = 1.45 g·cm^{-3}
Density of **F4** = 1 / {(0.15/1.8) + (0.85/1.38)} = 1.43 g·cm^{-3}
Density of **F8** = 1 / {(0.3/1.74) + (0.7/1.38)} = 1.47 g·cm^{-3}
Density of **F9** = 1 / {(0.25/1.74) + (0.75/1.38)} = 1.46 g·cm^{-3}
Density of **F10** = 1 / {(0.25/1.52) + (0.75/1.38)} = 1.41 g·cm^{-3}
Density of **F11** = 1 / {(0.15/1.52) + (0.85/1.38)} = 1.40 g·cm^{-3}

*For **Mn-Gu**,*
Oxidizer to fuel ratio for fuel **Mn-Gu** = 2
Density of fuel **Mn-Gu** propellant = 1 / {(0.33/1.8) + (0.67/1.41)} = 1.52 g·cm^{-3}
ρI_{sp} of fuel **Mn-Gu** propellant = 1.52 g·cm^{-3} x 228 s = **347 s·g·cm^{-3}**

*For **Cu-Gu**,*
Oxidizer to fuel ratio for fuel **Mn-Gu** = 1.5
Density of fuel **Mn-Gu** propellant = 1 / {(0.4/1.74) + (0.6/1.41)} = 1.53 g·cm^{-3}
ρI_{sp} of fuel **Mn-Gu** propellant = 1.53 g·cm^{-3} x 223 s = **341 s·g·cm^{-3}**

*For formulation **F1**,*
Oxidizer to fuel ratio for fuel **F1** = 1.25
Density of fuel **F1** propellant = 1 / {(0.44/1.48) + (0.56/1.41)} = 1.44 g·cm^{-3}
ρI_{sp} of fuel **F1** propellant = 1.44 g·cm^{-3} x 237 s = **341 s·g·cm^{-3}**

*For formulation **F2**,*
Oxidizer to fuel ratio for fuel **F2** = 1.15

Density of fuel **F2** propellant = 1 / {(0.465/1.47) + (0.535/1.41)} = 1.44 g·cm^{-3}
ρI_{sp} of fuel **F2** propellant = 1.44 g·cm^{-3} x 238 s = **343 s·g·cm^{-3}**

*For formulation **F3**,*
Oxidizer to fuel ratio for fuel **F3** = 1.1
Density of fuel **F3** propellant = 1 / {(0.476/1.45) + (0.524/1.41)} = 1.43 g·cm^{-3}
ρI_{sp} of fuel **F3** propellant = 1.43 g·cm^{-3} x 239 s = **342 s·g·cm^{-3}**

*For formulation **F4**,*
Oxidizer to fuel ratio for fuel **F4** = 1.0
Density of fuel **F4** propellant = 1 / {(0.5/1.43) + (0.5/1.41)} = 1.42 g·cm^{-3}
ρI_{sp} of fuel **F4** propellant = 1.42 g·cm^{-3} x 240 s = **341 s·g·cm^{-3}**

*For formulation **F8**,*
Oxidizer to fuel ratio for fuel **F8** = 1.15
Density of fuel **F8** propellant = 1 / {(0.465/1.47) + (0.535/1.41)} = 1.44 g·cm^{-3}
ρI_{sp} of fuel **F8** propellant = 1.44 g·cm^{-3} x 236 s = **340 s·g·cm^{-3}**

*For formulation **F9**,*
Oxidizer to fuel ratio for fuel **F9** = 1.10
Density of fuel **F9** propellant = 1 / {(0.476/1.46) + (0.524/1.41)} = 1.43 g·cm^{-3}
ρI_{sp} of fuel **F9** propellant = 1.43 g·cm^{-3} x 237 s = **339 s·g·cm^{-3}**

*For formulation **F10**,*
Oxidizer to fuel ratio for fuel **F10** = 1.50
Density of fuel **F10** propellant = 1 / {(0.4/1.41) + (0.6/1.41)} = 1.41 g·cm^{-3}
ρI_{sp} of fuel **F10** propellant = 1.41 g·cm^{-3} x 251 s = **354 s·g·cm^{-3}**

*For formulation **F11**,*
Oxidizer to fuel ratio for fuel **F11** = 1.20
Density of fuel **F11** propellant = 1 / {(0.45/1.40) + (0.55/1.41)} = 1.41 g·cm^{-3}
ρI_{sp} of fuel **F11** propellant = 1.41 g·cm^{-3} x 248 s = **350 s·g·cm^{-3}**