APPENDIX A

TEST RIG OPERATING DATA

Test Number	Average Rail Pressure (bar)	Standard Deviation Rail Pressure (bar)	Average Fuel Supply Temperature (°C)	Standard Deviation Fuel Supply Temperature (°C)	Average Fuel Inlet Temperature (°C)	Standard Deviation Fuel Inlet Temperature (°C)	Average Pump Drain Return Temperature (°C)	Standard Deviation Pump Drain Return Temperature (°C)	Average Fuel Rail Return Temperature (°C)	Standard Deviation Fuel Rail Return Temperature (°C)	Average Injector Return Temperature (°C)	Standard Deviation Injector Return Temperature (°C)	Average Injector Nozzle Nut Temperature 1 (°C)	Standard Deviation Injector Nozzle Nut Temperature 1 (°C)	Average Injector Nozzle Nut Temperature 2 (°C)	Standard Deviation Injector Nozzle Nut Temperature 2 (°C)	Overall Average Injector Nozzle Nut Temperature (°C)	Overall Standard Deviation Injector Nozzle Nut Temperature (°C)	Average Pump Speed (RPM)	Standard Deviation Pump Speed (RPM)	Fuel Weight Test Start (g)	Fuel Weight Test End (g)	Cumulative Fuel Injected (g)
CL18_2520-MT01	1800.0	0.56	29.35	0.26	30.00	0.19	53.77	0.66	135.0	0.35	115.7	2.90	200.0	0.38	200.0	0.39	200.0	0.36	1750.0	0.30	4373.6	2249.6	2124.0
CL18_2521-MT02	1800.0	0.50	29.40	0.25	30.00	0.19	53.32	0.42	134.9	0.33	116.6	2.94	204.5	0.62	195.5	0.57	200.0	0.35	1750.0	0.30	4426.6	2299.2	2127.4
CL18_2527-MT03	1800.0	0.52	29.65	0.26	30.00	0.20	52.74	0.24	134.5	0.16	128.2	0.91	189.1	0.48	210.9	0.49	200.0	0.36	1750.0	0.31	4400.2	2303.8	2096.4
CL18_2528-MT04	1800.0	0.80	29.66	0.23	30.00	0.16	52.43	0.40	133.4	0.26	105.0	3.00	197.0	0.33	203.0	0.35	200.0	0.31	1750.0	0.31	4529.4	2390.6	2138.8
CL18_2529-MT05	1800.0	0.63	29.52	0.21	30.00	0.16	52.67	0.39	133.9	0.51	130.4	1.61	200.5	0.43	199.5	0.34	200.0	0.33	1750.0	0.32	4518.6	2428.8	2089.8
CL18_2544-MT06	1800.0	0.77	29.39	0.21	29.99	0.17	53.56	0.33	134.8	0.26	130.5	1.67	204.5	0.33	195.5	0.42	200.0	0.30	1750.0	0.31	4392.4	2297.0	2095.4
CL18_2549-MT07	1800.0	0.74	29.42	0.22	30.00	0.17	53.45	0.23	133.8	0.32	117.4	2.52	198.2	0.62	201.8	0.59	200.0	0.49	1750.0	0.30	4487.4	2378.8	2108.6
CL18_2551-MT08	1800.0	0.74	29.45	0.21	30.00	0.17	53.90	0.27	134.5	0.22	109.1	2.12	194.8	0.64	205.1	0.71	200.0	0.61	1750.0	0.31	4602.6	2489.2	2113.4
CL18_2552-MT09	1800.0	0.93	29.51	0.17	30.00	0.12	53.58	0.32	133.8	0.29	101.4	3.22	195.4	0.41	204.7	0.51	200.0	0.36	1750.0	0.30	4424.6	2315.8	2108.8
CL18_2571-MT10	1800.0	0.79	29.72	0.16	30.00	0.14	53.04	0.40	134.0	0.17	111.9	1.51	197.2	1.18	202.7	1.20	199.9	1.18	1750.0	0.30	4500.6	2378.8	2121.8
CL18_2572-MT11	1800.0	1.65	29.49	0.21	30.00	0.17	53.00	0.35	133.6	0.25	105.9	3.02	196.6	0.52	203.4	0.61	200.0	0.50	1750.0	0.30	4427.4	2220.8	2206.6
CL18_2573-MT12	1800.0	0.50	29.54	0.16	30.00	0.13	52.65	0.37	134.4	0.19	129.2	1.50	196.8	0.50	203.2	0.55	200.0	0.29	1750.0	0.30	3939.2	1851.6	2087.6
CL18_2588-MT13	1800.0	0.92	29.60	0.22	30.00	0.15	53.08	0.26	133.6	0.27	110.8	3.75	201.9	0.49	198.1	0.46	200.0	0.45	1750.0	0.30	4149.6	2063.8	2085.8
CL18_2605-MT14	1800.0	0.74	29.79	0.18	30.00	0.15	51.99	0.20	133.9	0.22	128.8	3.43	207.5	0.96	192.4	0.70	200.0	0.65	1750.0	0.31	4023.2	1939.4	2083.8
CL18_2606-MT15	1800.0	0.84	29.70	0.22	30.00	0.16	52.07	0.28	133.4	0.32	110.2	4.71	194.8	1.34	205.0	1.30	199.9	1.27	1750.0	0.31	4134.0	2058.2	2075.8
CL18_2624-MT16	1800.0	2.56	29.64	0.24	30.00	0.16	52.38	0.19	133.8	0.24	116.0	4.75	199.4	0.63	200.6	0.63	200.0	0.54	1750.0	0.31	4229.6	2097.0	2132.6
CL18_2625-MT17	1800.0	0.63	29.49	0.21	30.00	0.14	52.67	0.22	134.1	0.25	116.2	4.74	197.3	1.39	202.5	1.44	199.9	1.38	1750.0	0.30	4022.4	1901.8	2120.6
CL18_2638-MT18	1800.0	0.57	29.54	0.19	30.00	0.15	50.99	0.20	133.6	0.23	115.4	4.21	191.9	0.73	208.1	0.80	200.0	0.68	1750.0	0.30	4088.0	1962.0	2126.0
CL18_2647-MT19	1800.0	0.70	29.61	0.24	30.00	0.15	53.74	0.42	134.4	0.41	117.0	6.05	197.3	1.03	202.6	0.93	200.0	0.96	1750.0	0.30	4107.8	2005.8	2102.0
CL18_2648-MT20	1800.0	0.82	29.61	0.23	30.00	0.14	52.14	0.29	133.7	0.43	127.8	4.45	192.1	1.13	206.4	1.19	199.3	1.14	1750.0	0.31	4106.8	2007.8	2099.0
CL18_2649-MT21	1800.0	0.78	29.66	0.23	30.00	0.14	52.92	0.18	134.2	0.31	118.3	6.93	196.3	1.55	203.4	1.57	199.8	1.50	1750.0	0.31	4078.2	2001.0	2077.2
CL18_2650-MT22	1800.0	3.81	29.44	0.21	30.00	0.14	52.89	0.49	133.8	0.40	120.5	5.08	207.0	0.74	192.9	0.64	200.0	0.63	1750.0	0.31	3994.4	1914.8	2079.6
CL18_2685-MT23	1799.8	3.33	30.40	1.92	30.88	1.71	54.09	1.84	135.3	1.23	128.2	7.65	193.5	4.20	200.6	4.18	197.0	4.16	1750.0	0.31	4136.4	1928.2	2208.2
CL18_2686-MT24	1799.9	1.96	29.48	0.21	30.00	0.14	52.48	0.26	134.3	0.28	120.5	5.24	204.8	2.15	194.7	1.90	199.8	1.99	1750.0	0.30	4106.4	1998.2	2108.2
CL18_2690-MT25	1799.9	1.40	29.57	0.22	30.00	0.15	52.75	0.26	134.1	0.35	108.4	4.67	193.8	2.25	205.9	2.07	199.8	2.13	1750.0	0.31	4093.6	1953.4	2140.2
CL18_2691-MT26	1800.0	1.00	29.66	0.23	30.00	0.16	50.77	0.16	133.5	0.22	108.5	3.68	203.3	0.84	196.6	0.77	200.0	0.77	1750.0	0.31	4164.8	2088.2	2076.6
CL18_2703-MT27	1800.0	1.10	29.47	0.22	30.00	0.13	52.33	0.20	134.5	0.32	129.6	3.54	196.0	1.74	197.3	1.73	196.6	1.72	1750.0	0.30	4063.8	1917.8	2146.0
CL18_2704-MT28	1800.0	1.76	29.45	0.20	30.00	0.13	53.11	0.20	134.5	0.33	119.2	5.18	195.8	0.61	204.1	0.70	200.0	0.61	1750.0	0.31	4065.0	1917.8	2147.2
CL18_2705-MT29	1800.0	1.80	29.56	0.19	30.00	0.14	52.18	0.18	134.3	0.32	126.8	3.75	200.1	1.43	199.6	0.99	199.8	1.11	1750.0	0.31	4070.2	1953.0	2117.2
CL18_2714-MT30	1800.0	1.14	29.60	0.22	30.00	0.15	52.05	0.36	133.5	0.34	107.1	4.15	193.5	0.51	206.6	0.61	200.0	0.47	1750.0	0.30	4108.8	1985.4	2123.4
CL18_2724-MT31	1800.0	1.04	29.63	0.24	30.00	0.18	52.49	0.38	133.8	0.36	106.4	4.42	201.8	2.06	197.8	1.99	199.8	2.02	1750.0	0.31	4151.8	2066.4	2085.4
CL18_2725-MT32	1800.0	0.76	29.53	0.21	30.00	0.14	53.16	0.29	134.2	0.32	120.2	4.22	196.2	0.66	203.7	0.74	200.0	0.67	1750.0	0.31	4068.2	1955.0	2113.2
CL18_2726-MT33	1800.0	0.98	29.56	0.23	30.00	0.14	52.69	0.29	134.1	0.37	118.1	5.50	191.3	0.49	208.7	0.56	200.0	0.40	1750.0	0.32	4159.2	2058.0	2101.2
CL18_2737-MT34	1800.0	0.69	29.70	0.19	30.00	0.13	52.62	0.17	133.8	0.28	119.2	4.31	198.6	1.10	201.2	1.10	199.9	1.09	1750.0	0.32	4082.6	1968.8	2113.8
CL18_2750-MT35	1800.0	0.67	29.57	0.25	30.00	0.17	52.24	0.31	134.3	0.34	129.2	3.44	204.3	1.81	192.9	1.41	198.6	1.57	1750.0	0.31	4156.6	2019.8	2136.8
CL18_2751-MT36	1800.0	0.63	29.59	0.21	30.00	0.14	52.87	0.49	134.1	0.37	112.7	3.71	193.7	1.34	206.1	1.44	199.9	1.32	1750.0	0.32	4096.8	2007.4	2089.4
CL18_2752-MT37	1800.0	0.71	29.57	0.21	30.00	0.14	53.25	0.33	134.3	0.34	117.2	4.21	197.7	1.72	202.1	1.86	199.9	1.77	1750.0	0.32	4039.0	1892.2	2146.8
CL18_2753-MT38	1800.0	0.56	29.51	0.21	30.00	0.14	52.87	0.26	134.6	0.40	130.8	3.76	199.1	2.27	195.6	1.21	197.4	1.70	1750.0	0.29	4085.4	1999.0	2086.4
CL18_2799-MT39	1800.0	0.74	29.63	0.20	30.00	0.14	52.12	0.35	133.4	0.32	110.4	3.93	194.8	0.92	205.1	0.90	200.0	0.87	1750.0	0.31	4195.0	2096.2	2098.8
CL18_2800-MT40	1800.0	0.69	29.69	0.19	30.00	0.15	52.41	0.29	133.2	0.28	112.1	3.91	199.3	1.06	200.6	1.17	199.9	1.10	1750.0	0.31	4157.2	2049.6	2107.6
CL18_2801-MT41	1800.0	0.71	29.65	0.21	30.00	0.14	52.41	0.24	133.3	0.33	118.2	3.25	203.4	0.83	196.6	0.75	200.0	0.77	1750.0	0.32	4204.2	2116.6	2087.6
CL18_2802-MT42	1800.0	0.71	29.57	0.21	30.00	0.14	53.47	0.36	134.2	0.33	116.1	3.27	201.5	1.90	198.1	1.82	199.8	1.85	1750.0	0.32	3851.4	1708.6	2142.8
CL18_2835-MT43	1800.0	0.75	29.53	0.22	30.00	0.14	52.67	0.25	133.8	0.29	112.2	3.33	203.5	1.10	196.4	1.07	199.9	1.07	1750.0	0.32	4157.0	2040.8	2116.2
CL18_2836-MT44	1799.9	0.60	29.55	0.23	30.00	0.14	52.60	0.20	134.2	0.35	124.2	5.21	201.7	1.39	198.1	1.21	199.9	1.07	1750.0	0.32	4093.0	1983.8	2109.2
CL18_2837-MT45	1800.0	0.67	29.67	0.21	30.00	0.14	50.94	0.51	132.7	0.43	109.4	4.74	197.5	0.61	202.5	0.60	200.0	0.59	1750.0	0.32	4152.0	2032.8	2119.2
CL18_2838-MT46	1799.9	0.79	29.63	0.44	29.97	0.38	50.92	0.47	133.0	0.40	113.1	5.38	198.7	1.88	201.0	1.77	199.9	1.81	1750.0	0.30	4268.0	2117.0	2151.0
CL18_2883-MT47	1799.9	0.78	29.62	0.21	30.00	0.17	55.02	3.86	134.4	1.37	110.5	5.04	191.9	0.79	208.1	0.80	200.0	0.54	1750.0	0.31	4207.0	2087.8	2119.2
CL18_2884-MT48	1800.0	0.78	29.51	0.22	30.00	0.17	52.97	0.50	134.1	0.43	119.0	5.23	199.2	2.11	200.3	2.06	199.8	2.08	1750.0	0.31	4145.0	2018.4	2126.6
CL18_2885-MT49	1800.0	0.70	29.69	0.17	30.00	0.15	50.02	0.34	133.3	0.34	112.3	4.23	198.2	1.12	201.7	1.27	199.9	1.18	1750.0	0.31	4072.4	1971.2	2101.2
CL18_2886-MT50	1800.0	0.92	29.47	0.26	30.00	0.16	53.03	0.26	134.8	0.43	130.2	3.69	202.1	1.53	197.6	0.90	199.8	1.16	1750.0	0.30	4137.2	2009.8	2127.4
CL18_2910-MT51	1800.0	0.85	29.86	0.19	30.00	0.16	53.04	0.33	134.1	0.32	119.9	4.41	194.4	0.83	205.5	0.72	200.0	0.68	1750.0	0.31	4097.2	1945.0	2152.2
CL18_2911-MT52	1800.0	0.55	29.88	0.21	30.00	0.15	51.62	0.20	133.6	0.25	105.1	3.45	200.4	0.78	199.5	0.71	200.0	0.74	1750.0	0.31	4165.0	2048.2	2116.8
CL18_2912-MT53	1800.0	0.54	29.86	0.18	30.01	0.15	51.71	0.23	133.2	0.27	104.1	5.39	196.0	0.62	204.0	0.65	200.0	0.53	1750.0	0.31	4045.4	1929.2	2116.2
CL18_2915-MT54	1800.0	0.74	29.64	0.20	30.00	0.16	53.10	0.37	134.9	0.44	130.8	3.70	209.2	1.81	188.9	2.00	199.0	1.89	1750.0	0.31	4164.0	2046.6	2117.4
CL18_2927-MT55	1800.0	0.60	29.54	0.23	30.01	0.17	53.00	0.47	133.9	0.36	107.5	3.47	197.4	1.24	202.5	1.15	199.9	1.17	1750.0	0.30	4172.6	2064.0	2108.6
CL18_2928-MT56	1800.0	0.62	29.57	0.22	30.00	0.17	53.84	0.32	134.6	0.30	121.5	5.85	195.6	1.11	204.3	1.09	200.0	1.01	1750.0	0.30	4160.8	2056.0	2104.8
CL18_2929-MT57	1800.0	0.55	29.67	0.17	30.00	0.15	52.98	0.27	133.6	0.19	111.4	2.30	206.9	0.78	193.1	0.63	200.0	0.64	1750.0	0.3	4116.6	1997.6	2119.0
CL18_2930-MT58	1800.0	0.60	29.48	0.20	30.00	0.15	52.86	0.28	134.7	0.33	128.6	2.78	203.4	1.39	196.4	0.93	199.9	1.07	1750.0	0.3	4084.2	2012.0	2072.2
CL18_2951-MT59	1800.0	0.60	29.55	0.20	30.00	0.16	53.05	0.32	134.3	0.30	114.0	5.23	196.6	0.78	203.3	0.84	200.0	0.79	1750.0	0.3	4164.0	2013.4	2150.6
CL18_2952-MT60	1800.0	0.65	29.52	0.23	30.00	0.15	53.21	0.44	133.9	0.50	116.7	5.02	190.1	1.05	209.9	1.06	200.0	0.92	1750.0	0.3	4120.4	2020.2	2100.2
CL18_2953-MT61	1800.0	0.91	29.70	0.22	30.00	0.16	49.86	0.21	133.4	0.35	127.6	3.46	195.9	1.80	203.8	1.28	199.9	1.42	1750.0	0.3	3916.0	1834.4	2081.6
CL18_2954-MT62	1800.0	0.63	29.86	0.52	30.11	0.47	53.02	0.53	134.0	0.48	121.1	3.25	199.4	1.15	200.5	0.84	199.9	0.96	1750.0	0.3	4175.0	2029.6	2145.4
CL18_2971-MT63	1800.0	0.59	29.71	0.22	30.00	0.17	53.26	0.31	134.0	0.33	116.1	3.99	199.2	1.64	200.5	1.66	199.8	1.64	1750.0	0.3	4106.6	2014.8	2091.8
CL18_2972-MT64	1800.0	0.52	29.71	0.23	30.00	0.16	52.67	0.34	133.4	0.39	113.6	3.58	201.0	1.05	198.9	1.05	199.9	1.04	1750.0	0.3	4231.6	2094.0	2137.6
CL19_3475-MT65	1800.0	0.63	30.10	0.17	30.00	0.14	50.53	0.22	132.5	0.17	106.1	2.59	198.4	0.59	201.6	0.63	200.0	0.60	1750.0	0.3	4059.0	1952.8	2106.2
CL19_3500-MT66	1800.0	0.57	30.06	0.17	30.00	0.14	51.03	0.22	132.7	0.20	106.4	2.00	196.2	0.43	203.8	0.48	200.0	0.42	1750.0	0.3	3993.6	1897.2	2096.4
CL19_3501-MT67	1800.0	0.57	30.03	0.18	30.00	0.14	51.62	0.20	133.0	0.21	117.2	3.01	190.3	0.52	209.7	0.56	200.0	0.38	1750.0	0.3	4118.0	2030.4	2087.6
CL19_3518-MT68	1800.0	0.61	30.07	0.17	30.00	0.14	51.84	0.22	133.1	0.24	104.5	3.29	202.3	0.56	197.7	0.53	200.0	0.53	1750.0	0.3	4120.6	2006.6	2114.0
CL19_3560-MT69	1800.0	0.64	30.16	0.16	30.00	0.12	52.45	0.33	133.3	0.17	126.2	0.77	189.8	0.31	210.2	0.32	200.0	0.18	1750.0	0.3	4068.6	1915.2	2153.4
CL19_3561-MT70	1800.0	0.55	30.37	0.22	30.00	0.13	52.03	0.26	132.8	0.31	100.5	3.20	199.6	0.59	200.4	0.59	200.0	0.58	1750.0	0.3	4033.8	1894.6	2139.2

APPENDIX B

MATRIX TESTS – FUEL BLEND MATRIX AND PINTLE CODES

Matrix		Factors (Additives)								
Test No.	Pattern	Biodiesel	Sodium	Glycerin	Corrosion Inibitor	Lubricity Additive	Injector Sticking Additive	Cetane Number Improver	Conductivity Additive	Number of Additives
1	−+−−−+−−	No	Yes	No	No	No	Yes	No	No	2
2	−−−+−+−+	No	No	No	Yes	No	Yes	No	Yes	3
3	−++++++−	No	Yes	Yes	Yes	Yes	Yes	Yes	No	6
4	+−−+−−++	Yes	No	No	Yes	No	No	Yes	Yes	4
5	++−−+++−	Yes	Yes	No	No	Yes	Yes	Yes	No	5
6	−+−++−++	No	Yes	No	Yes	Yes	No	Yes	Yes	5
7	+−−+−+−−	Yes	No	No	Yes	No	Yes	No	No	3
8	−+−−++++	No	Yes	No	No	Yes	Yes	Yes	Yes	5
9	++++++++	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	8
10	−++−+−+−	No	Yes	Yes	No	Yes	No	Yes	No	4
11	+−−−−−−−	Yes	No	No	No	No	No	No	No	1
12	−−++−−−−	No	No	Yes	Yes	No	No	No	No	2
13	+−+−+++−	Yes	No	Yes	No	Yes	Yes	Yes	No	5
14	−+++−−+−	No	Yes	Yes	Yes	No	No	Yes	No	4
15	++−+−++−	Yes	Yes	No	Yes	No	Yes	Yes	No	5
16	−++++−−+	No	Yes	Yes	Yes	Yes	No	No	Yes	5
17	−−+−+−−−	No	No	Yes	No	Yes	No	No	No	2
18	++−+−−−+	Yes	Yes	No	Yes	No	No	No	Yes	4
19	−−−++++−	No	No	No	Yes	Yes	Yes	Yes	No	4
20	+−+++−+−	Yes	No	Yes	Yes	Yes	No	Yes	No	5
21	−−+−−+−−	No	No	Yes	No	No	Yes	No	No	2
22	++++−+−−	Yes	Yes	Yes	Yes	No	Yes	No	No	5
23	−−++−+++	No	No	Yes	Yes	No	Yes	Yes	Yes	5
24	−+−−−−++	No	Yes	No	No	No	No	Yes	Yes	3
25	+−−++−−−	Yes	No	No	Yes	Yes	No	No	No	3
26	−−−+−−+−	No	No	No	Yes	No	No	Yes	No	2
27	−+++−+−+	No	Yes	Yes	Yes	No	Yes	No	Yes	5
28	+−−−+++	Yes	No	No	No	No	Yes	Yes	Yes	4
29	−−−−−−−+	No	No	No	No	No	No	No	Yes	1
30	+++−+−++	Yes	Yes	Yes	No	Yes	No	Yes	Yes	6
31	−−+++−++	No	No	Yes	Yes	Yes	No	Yes	Yes	5
32	−+−+−+++	No	Yes	No	Yes	No	Yes	Yes	Yes	5
33	−+−+++−−	No	Yes	No	Yes	Yes	Yes	No	No	4
34	+−++−++−	Yes	No	Yes	Yes	No	Yes	Yes	No	5
35	−−−+−+−−	No	No	No	No	Yes	No	Yes	No	2
36	−++−++−+	No	Yes	Yes	No	Yes	Yes	No	Yes	5
37	−+−−+−−−	No	Yes	No	No	Yes	No	No	No	2
38	+−−−+−++	Yes	No	No	No	Yes	No	Yes	Yes	4
39	+−+−+−−+	Yes	No	Yes	No	Yes	No	No	Yes	4
40	+−+−−−+−	Yes	No	Yes	No	No	No	Yes	No	3
41	+++−−−−−	Yes	Yes	Yes	No	No	No	No	No	3
42	−−++++−−	No	No	Yes	Yes	Yes	Yes	No	No	4
43	++−−−−+−	Yes	Yes	No	No	No	No	Yes	No	3
44	−++−−−−+	No	Yes	Yes	No	No	No	No	Yes	3
45	++−−−+−+	Yes	Yes	No	No	No	Yes	No	Yes	4
46	++++−−++	Yes	Yes	Yes	Yes	No	No	Yes	Yes	6
47	+−++++−+	Yes	No	Yes	Yes	Yes	Yes	No	Yes	6
48	+++−−+++	Yes	Yes	Yes	No	No	Yes	Yes	Yes	6
49	++−+++−+	Yes	Yes	No	Yes	Yes	Yes	No	Yes	6
50	−−−++−−+	No	No	No	Yes	Yes	No	No	Yes	3
51	−−+−++++	No	No	Yes	No	Yes	Yes	Yes	Yes	5
52	−+−+−−−−	No	Yes	No	Yes	No	No	No	No	2
53	+++++−−−	Yes	Yes	Yes	Yes	Yes	No	No	No	5
54	−−−−++−+	No	No	No	No	Yes	Yes	No	Yes	3
55	+++−++−−	Yes	Yes	Yes	No	Yes	Yes	No	No	5
56	−−−−−++−	No	No	No	No	No	Yes	Yes	No	2
57	+−−−++−−	Yes	No	No	No	Yes	Yes	No	No	3
58	−−+−−−++	No	No	Yes	No	No	No	Yes	Yes	3
59	−++−−++−	No	Yes	Yes	No	No	Yes	Yes	No	4
60	+−−+++++	Yes	No	No	Yes	Yes	Yes	Yes	Yes	6
61	++−−+−−+	Yes	Yes	No	No	Yes	No	No	Yes	4
62	+−++−−−+	Yes	No	Yes	Yes	No	No	No	Yes	4
63	+−+−−+−+	Yes	No	Yes	No	No	Yes	No	Yes	4
64	++−++−+−	Yes	Yes	No	Yes	Yes	No	Yes	No	5
65	−+++−−+−	No	Yes	Yes	Yes	No	No	Yes	No	4
66	−−+++−++	No	No	Yes	Yes	Yes	No	Yes	Yes	5
67	++−++−+−	Yes	Yes	No	Yes	Yes	No	Yes	No	5
68	++−++−+−	Yes	Yes	No	Yes	Yes	No	Yes	No	5
69	−−+++−++	No	No	Yes	Yes	Yes	No	Yes	Yes	5
70	−+++−−+−	No	Yes	Yes	Yes	No	No	Yes	No	4

Injector and Pintle Identification for Rig Matrix Tests

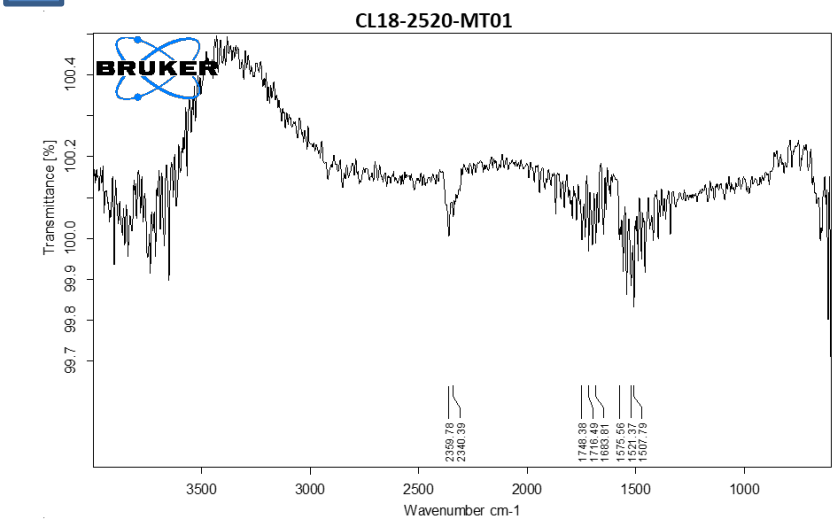
CRC Run #	SwRI Run #	SwRI Fuel #	SwRI Test #	Injector Serial Number	Test Date	Pintle Code
1	MT01	CL18-2520	CL18_2520-MT01	1792KL25F54	6/14/2018	21
2	MT02	CL18-2521	CL18_2521-MT02	1689KL25F64	6/15/2018	22
3	MT03	CL18-2527	CL18_2527-MT03	1798KL25F64	6/20/2018	23
4	MT04	CL18-2528	CL18_2528-MT04	1679KL25F64	6/21/2018	24
5	MT05	CL18-2529	CL18_2529-MT05	1645KL25F64	6/22/2018	25
6	MT06	CL18-2544	CL18_2544-MT06	1665KL25F54	6/27/2018	26
7	MT07	CL18-2549	CL18_2549-MT07	1593KL25F44	6/28/2018	27
8	MT08	CL18-2551	CL18_2551-MT08	1701KL25F64	6/29/2018	28
9	MT09	CL18-2552	CL18_2552-MT09	1660KL25F44	6/30/2018	29
10	MT10	CL18-2571	CL18_2571-MT10	1671KL25F54	7/4/2018	30
11	MT11	CL18-2572	CL18_2572-MT11	1644KL25F44	7/5/2018	31
12	MT12	CL18-2573	CL18_2573-MT12	1793KL25F64	7/6/2018	32
13	MT13	CL18-2588	CL18_2588-MT13	1974KL25F44	7/7/2018	33
14	MT14	CL18-2605	CL18_2605-MT14	1736KL25F64	7/9/2018	34
15	MT15	CL18-2606	CL18_2606-MT15	1687KL25F44	7/10/2018	35
16	MT16	CL18-2624	CL18_2624-MT16	1742KL25F64	7/11/2018	36
17	MT17	CL18-2625	CL18_2625-MT17	1693KL25F44	7/14/2018	37
18	MT18	CL18-2638	CL18_2638-MT18	1605KL25F44	7/15/2018	38
19	MT19	CL18-2647	CL18_2647-MT19	1766KL25F64	7/18/2018	39
20	MT20	CL18-2648	CL18_2648-MT20	0719JL20F54	7/19/2018	40
21	MT21	CL18-2649	CL18_2649-MT21	1725KL25F64	7/20/2018	41
22	MT22	CL18-2650	CL18_2650-MT22	1810KL25F64	7/21/2018	42
23	MT23	CL18-2685	CL18_2685-MT23	1730KL25F44	7/23/2018	43
24	MT24	CL18-2686	CL18_2686-MT24	1789KL25F54	7/24/2018	44
25	MT25	CL18-2690	CL18_2690-MT25	1809KL25F64	7/25/2018	45
26	MT26	CL18-2691	CL18_2691-MT26	1962KL25F44	7/28/2018	46
27	MT27	CL18-2703	CL18_2703-MT27	1710KL25F44	7/29/2018	47
28	MT28	CL18-2704	CL18_2704-MT28	1739KL25F64	7/30/2018	48
29	MT29	CL18-2705	CL18_2705-MT29	1985KL25F64	7/31/2018	49
30	MT30	CL18-2714	CL18_2714-MT30	1776KL25F44	8/1/2018	50
31	MT31	CL18-2724	CL18_2724-MT31	1963KL25F54	8/6/2018	51
32	MT32	CL18-2725	CL18_2725-MT32	1716KL25F54	8/7/2018	52
33	MT33	CL18-2726	CL18_2726-MT33	1788KL25F44	8/8/2018	53
34	MT34	CL18-2737	CL18_2737-MT34	1699KL25F44	8/10/2018	54
35	MT35	CL18-2750	CL18_2750-MT35	1987KL25F54	8/13/2018	55
36	MT36	CL18-2751	CL18_2751-MT36	1785KL25F54	8/14/2018	56
37	MT37	CL18-2752	CL18_2752-MT37	0721JL20F54	8/15/2018	57
38	MT38	CL18-2753	CL18_2753-MT38	1365KL25F44	8/16/2018	58
39	MT39	CL18-2799	CL18_2799-MT39	1830KL25F64	8/20/2018	59
40	MT40	CL18-2800	CL18_2800-MT40	1961KL25F64	8/21/2018	60

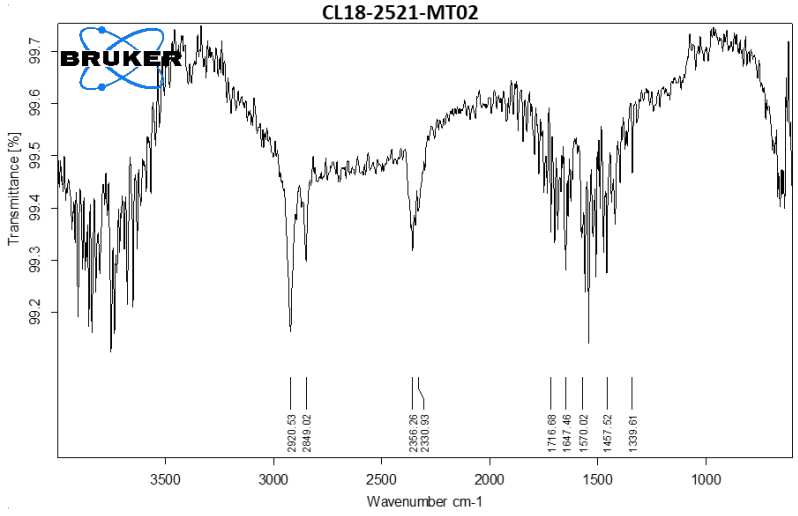
Injector and Pintle Identification for Rig Matrix Tests cont'd

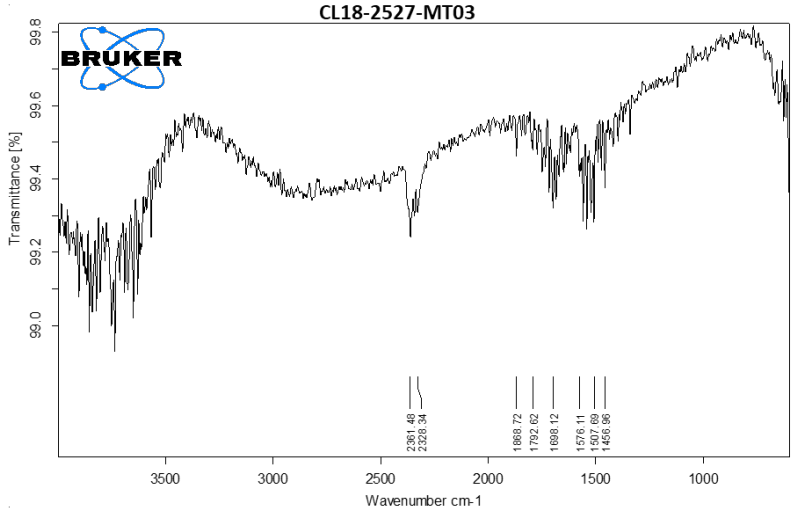
CRC Run #	SwRI Run #	SwRI Fuel #	SwRI Test #	Injector Serial Number	Test Date	Pintle Code
41	MT41	CL18-2801	CL18_2801-MT41	1599KL25F44	8/22/2018	61
42	MT42	CL18-2802	CL18_2802-MT42	1827KL25F54	8/23/2018	62
43	MT43	CL18-2835	CL18_2835-MT43	1767KL25F44	8/27/2018	63
44	MT44	CL18-2836	CL18_2836-MT44	1969KL25F54	8/28/2018	64
45	MT45	CL18-2837	CL18_2837-MT45	1633KL25F64	8/29/2018	65
46	MT46	CL18-2838	CL18_2838-MT46	1986KL25F44	8/30/2018	66
47	MT47	CL18-2883	CL18_2883-MT47	1805KL25F64	9/4/2018	67
48	MT48	CL18-2884	CL18_2884-MT48	1639KL25F44	9/5/2018	68
49	MT49	CL18-2885	CL18_2885-MT49	1512KL25F44	9/6/2018	69
50	MT50	CL18-2886	CL18_2886-MT50	1751KL25F64	9/7/2018	70
51	MT51	CL18-2910	CL18_2910-MT51	1653KL25F44	9/10/2018	71
52	MT52	CL18-2911	CL18_2911-MT52	1954KL25F54	9/11/2018	72
53	MT53	CL18-2912	CL18_2912-MT53	1800KL25F64	9/12/2018	73
54	MT54	CL18-2915	CL18_2915-MT54	1784KL25F64	9/13/2018	74
55	MT55	CL18-2927	CL18_2927-MT55	1885KL25F44	9/18/2018	75
56	MT56	CL18-2928	CL18_2928-MT56	1356KL25F44	9/19/2018	76
57	MT57	CL18-2929	CL18_2929-MT57	1829KL25F54	9/20/2018	77
58	MT58	CL18-2930	CL18_2930-MT58	2899LL14F64	9/21/2018	78
59	MT59	CL18-2951	CL18_2951-MT59	1702KL25F44	9/24/2018	79
60	MT60	CL18-2952	CL18_2952-MT60	1839KL25F54	9/25/2018	80
61	MT61	CL18-2953	CL18_2953-MT61	0714JL20F44	9/26/2018	81
62	MT62	CL18-2954	CL18_2954-MT62	1607KL25F64	9/27/2018	82
63	MT63	CL18-2971	CL18_2971-MT63	1956KL25F44	9/30/2018	83
64	MT64	CL18-2972	CL18_2972-MT64	1993BL06F44	10/3/2018	84
65	MT65	CL19-3475	CL19_3475-MT65	1790KL25F64	2/1/2019	85
66	MT66	CL19-3500	CL19_3500-MT66	1595KL25F64	2/3/2019	86
67	MT67	CL19-3501	CL19_3501-MT67	1756KL25F54	2/6/2019	87
68	MT68	CL19-3518	CL19_3518-MT68	1622KL25F44	2/7/2019	88
69	MT69	CL19-3560	CL19_3560-MT69	3651LL14F64	2/19/2019	89
70	MT70	CL19-3561	CL19_3561-MT70	1753KL25F54	2/20/2019	90

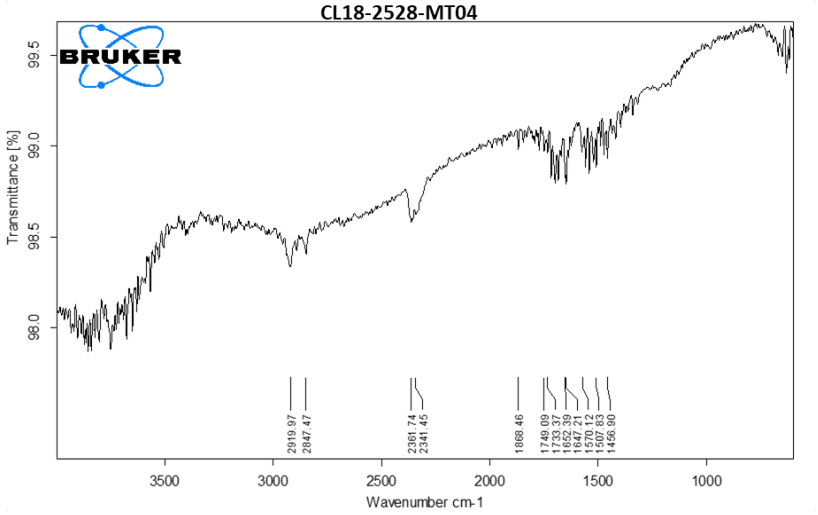
APPENDIX C

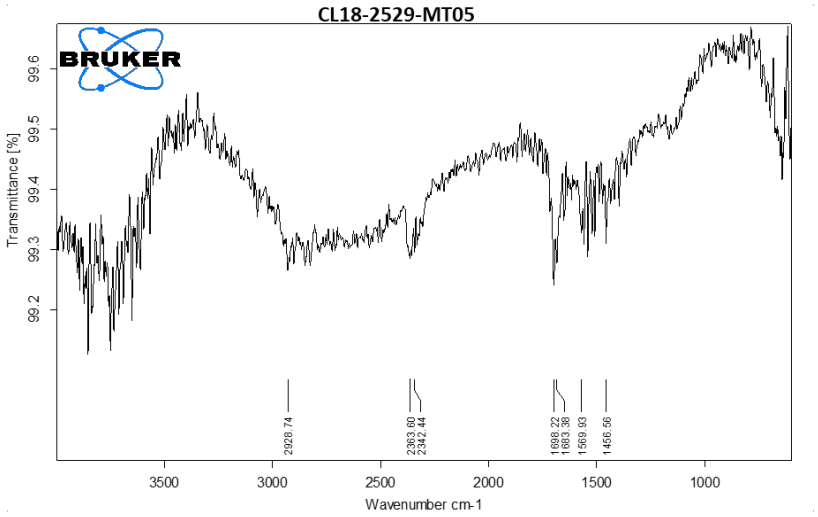
FTIR SPECTRA OF MATRIX TEST PINTLE DEPOSITS

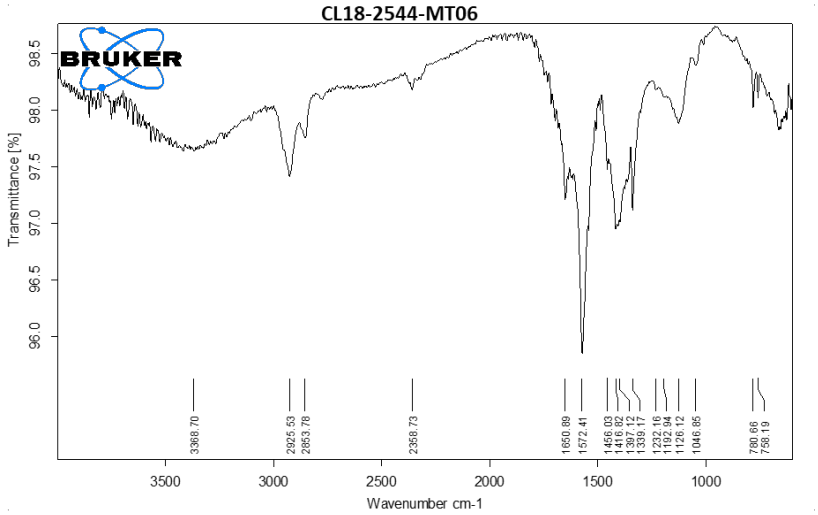

CL18-2520-MT01
BRUKER
Transmittance [%]
100.4
100.2
100.0
99.9
99.8
99.7
2359.78
2340.39
1748.38
1716.49
1683.81
1575.56
1521.37
1507.79
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

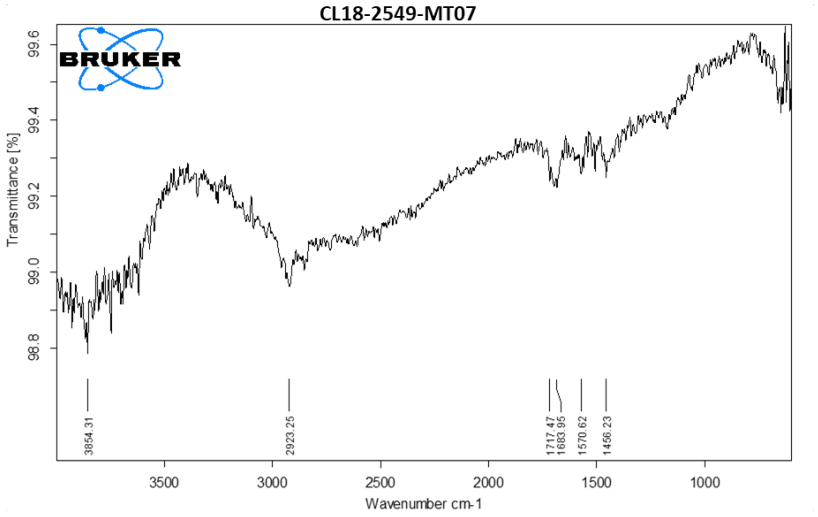

CL18-2521-MT02
BRUKER
Transmittance [%]
99.7
99.6
99.5
99.4
99.3
99.2
2920.53
2849.02
2356.26
2330.93
1716.68
1647.46
1570.02
1457.52
1339.61
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

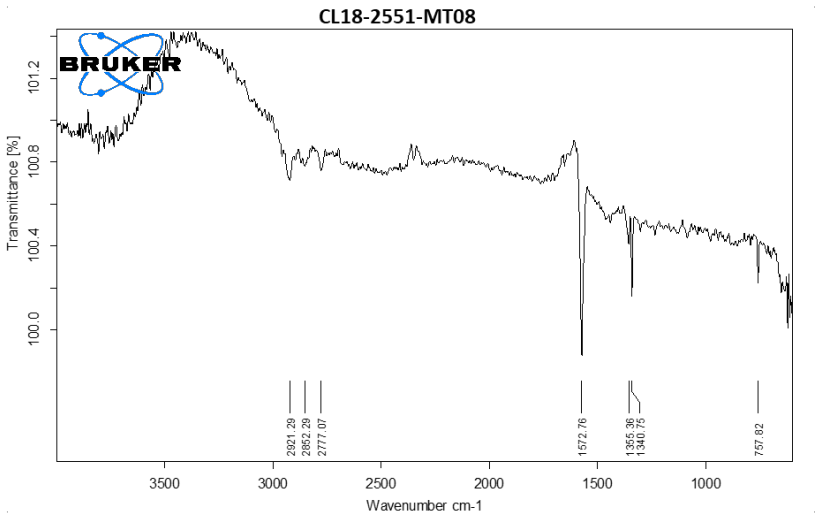

CL18-2527-MT03
BRUKER
Transmittance [%]
99.8
99.6
99.4
99.2
99.0
2361.48
2328.34
1868.72
1792.62
1698.12
1576.11
1507.69
1456.96
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

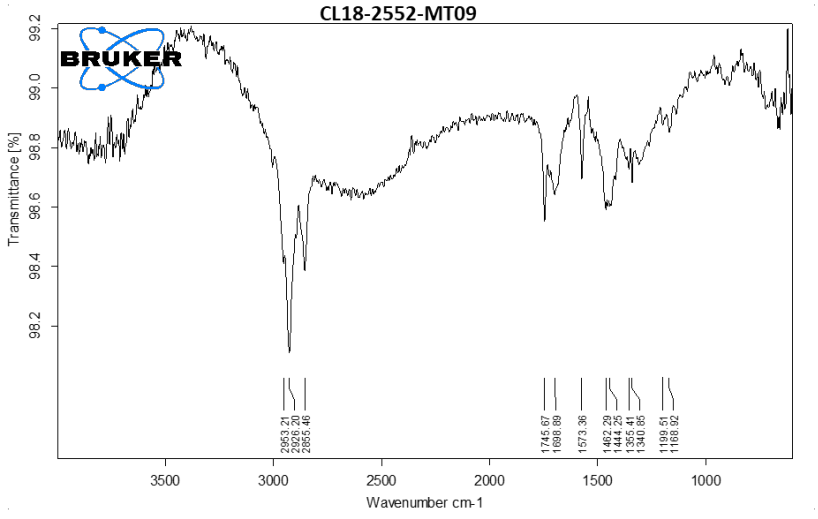

CL18-2528-MT04
BRUKER
Transmittance [%]
99.5
99.0
98.5
98.0
2919.97
2847.47
2361.74
2341.45
1868.46
1749.09
1733.37
1692.39
1647.71
1570.12
1507.83
1456.90
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

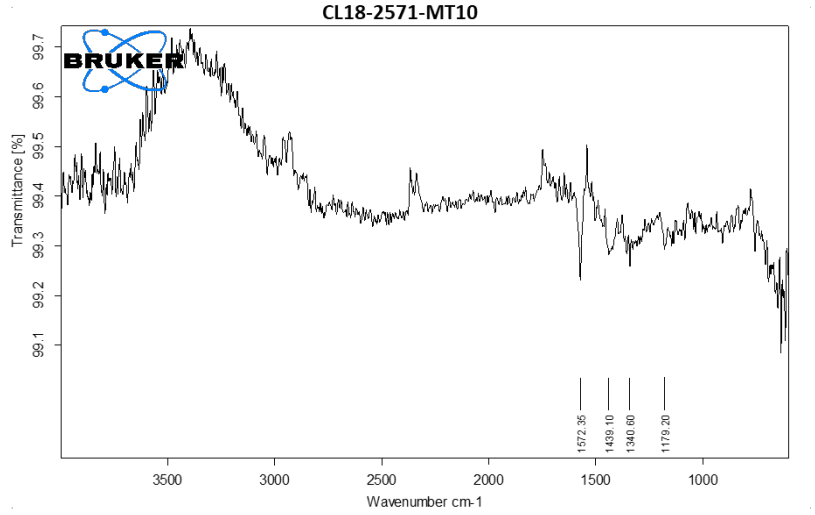

CL18-2529-MT05
BRUKER
Transmittance [%]
99.6
99.5
99.4
99.3
99.2
2928.74
2363.60
2342.44
1688.22
1683.38
1569.93
1456.56
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

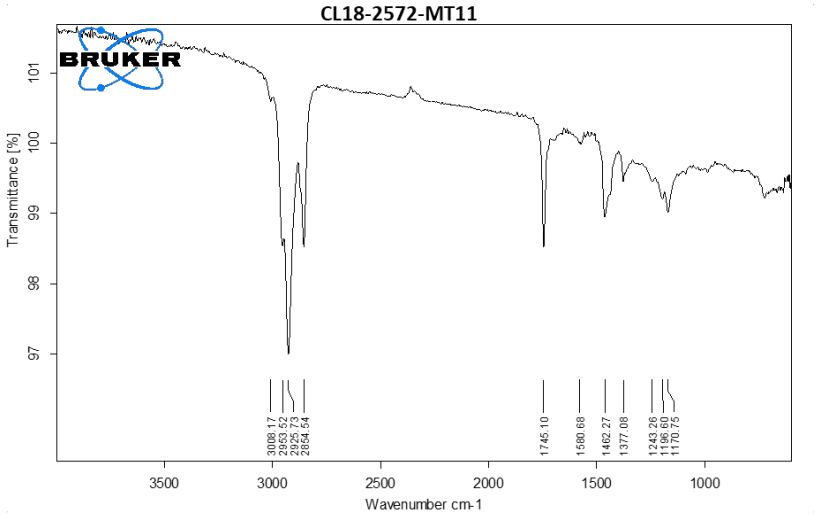

CL18-2544-MT06
BRUKER
Transmittance [%]
98.5
98.0
97.5
97.0
96.5
96.0
3368.70
2925.53
2853.78
2368.73
1650.89
1572.41
1456.03
1445.82
1397.12
1339.17
1232.16
1192.94
1126.12
1046.85
780.66
758.19
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

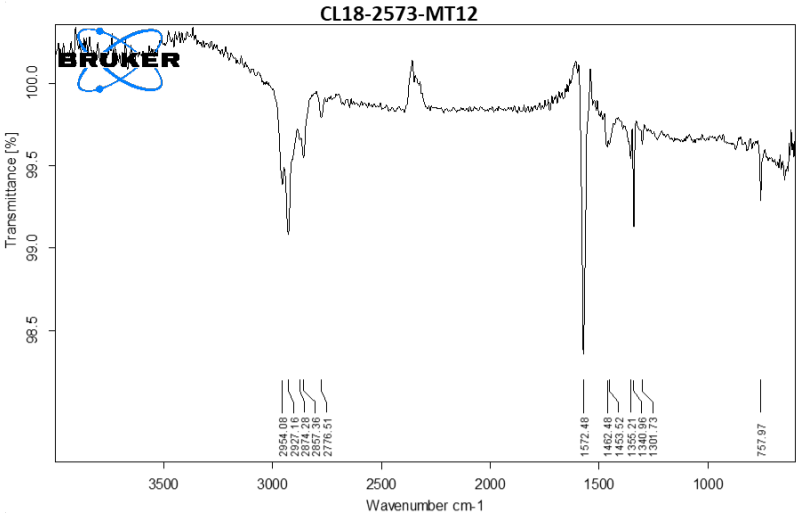

CL18-2549-MT07
BRUKER
Transmittance [%]
99.6
99.4
99.2
99.0
98.8
3854.31
2923.25
1717.47
1683.95
1570.62
1456.23
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

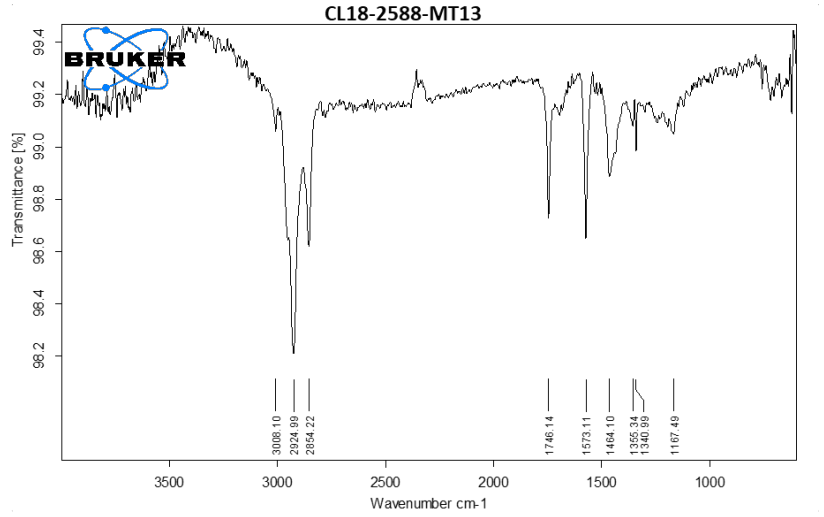

CL18-2551-MT08
BRUKER
Transmittance [%]
101.2
100.8
100.4
100.0
2921.29
2852.29
2777.07
1572.76
1355.36
1340.75
757.82
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

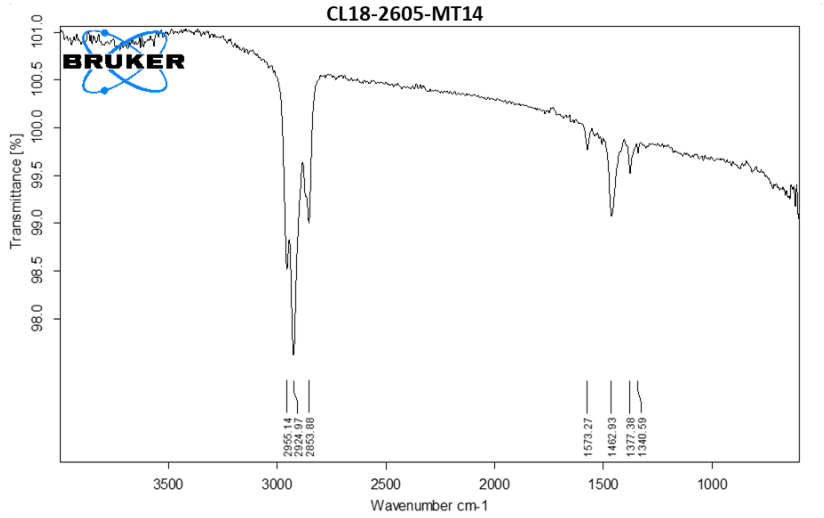

CL18-2552-MT09
BRUKER
Transmittance [%]
99.2
99.0
98.8
98.6
98.4
98.2
2953.21
2926.20
2855.46
1745.67
1698.89
1573.36
1462.29
1444.25
1355.41
1340.85
1189.51
1168.92
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

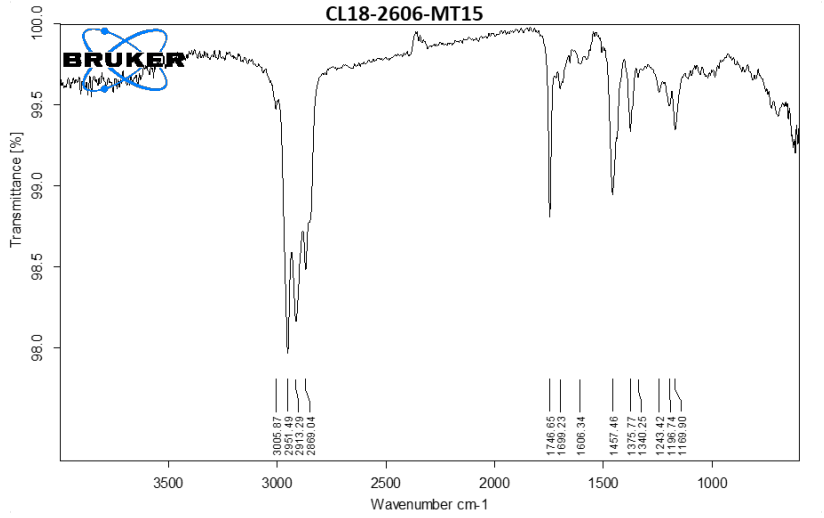

CL18-2571-MT10
BRUKER
Transmittance [%]
99.7
99.6
99.5
99.4
99.3
99.2
99.1
1572.35
1439.10
1340.60
1179.20
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

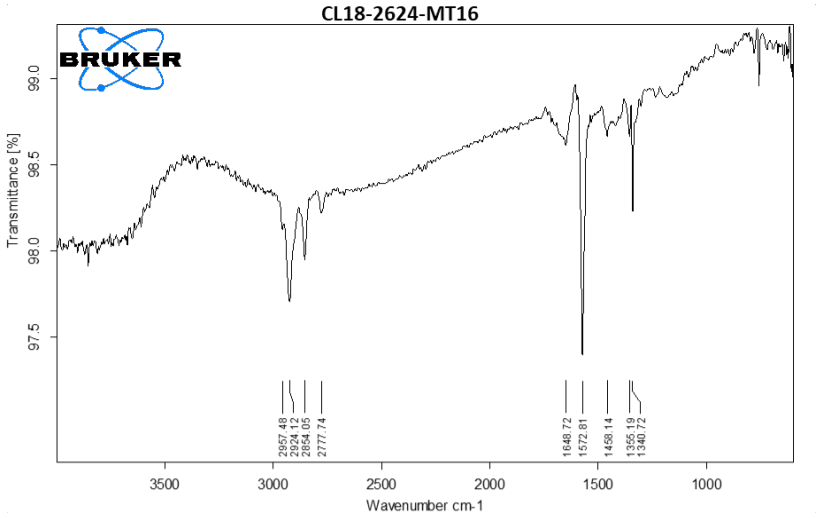

CL18-2572-MT11
BRUKER
Transmittance [%]
101
100
99
98
97
3008.17
2953.52
2925.73
2854.54
1745.10
1580.68
1462.27
1377.08
1243.26
1196.60
1170.75
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

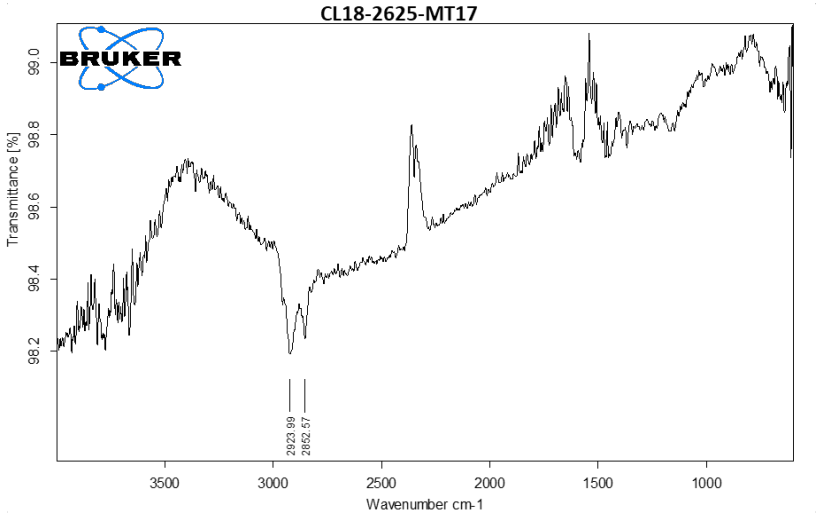

CL18-2573-MT12
BRUKER
Transmittance [%]
100.0
99.5
99.0
98.5
2954.08
2927.16
2874.28
2857.36
2776.51
1572.48
1462.48
1443.52
1355.21
1340.96
1301.73
757.97
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

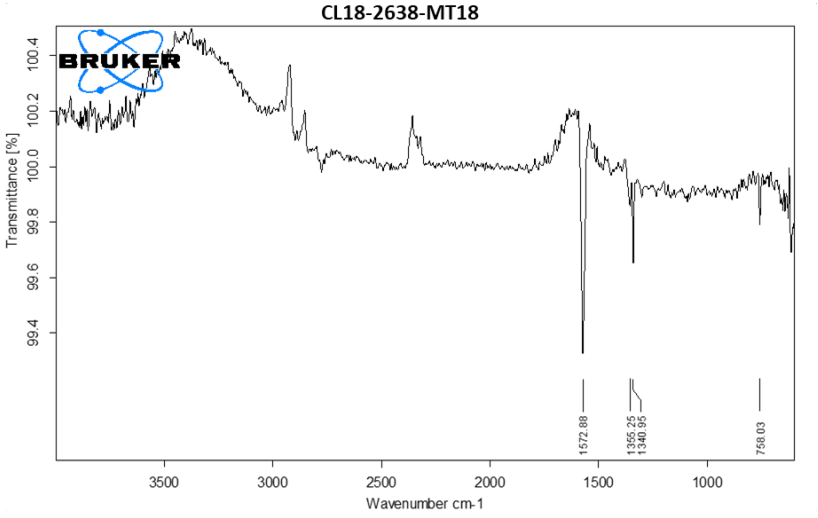

CL18-2588-MT13
BRUKER
Transmittance [%]
99.4
99.2
99.0
98.8
98.6
98.4
98.2
3008.10
2924.99
2854.22
1746.14
1573.11
1464.10
1355.34
1340.99
1167.49
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

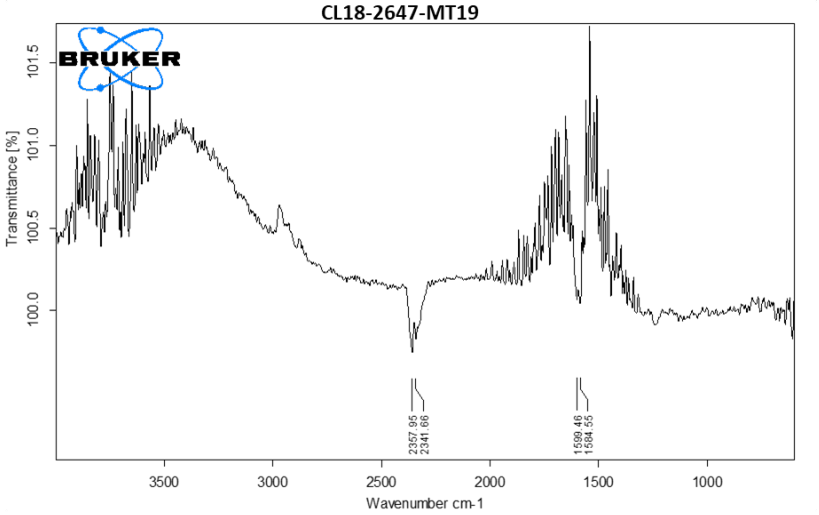

CL18-2605-MT14
BRUKER
Transmittance [%]
101.0
100.5
100.0
99.5
99.0
98.5
98.0
2955.14
2924.97
2853.88
1573.27
1462.93
1377.38
1340.59
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

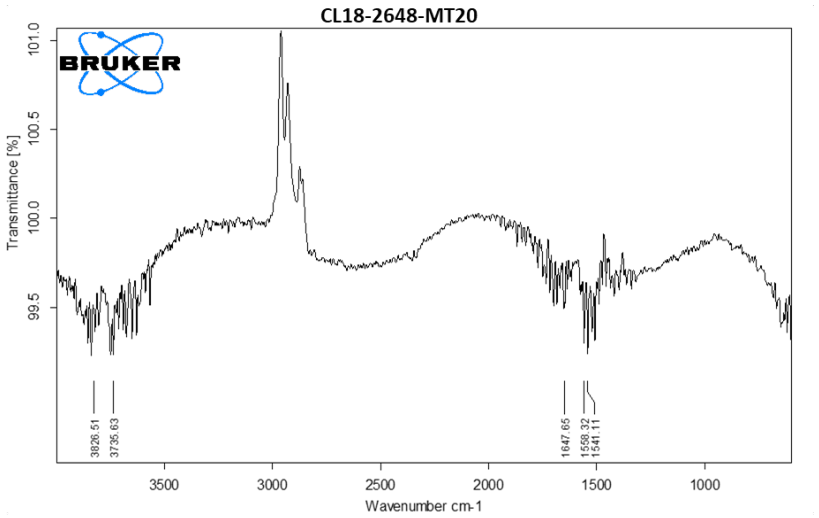

CL18-2606-MT15
BRUKER
Transmittance [%]
100.0
99.5
99.0
98.5
98.0
3005.87
2955.49
2913.29
2869.04
1746.65
1699.23
1606.34
1457.46
1375.77
1340.25
1243.42
1196.74
1169.90
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

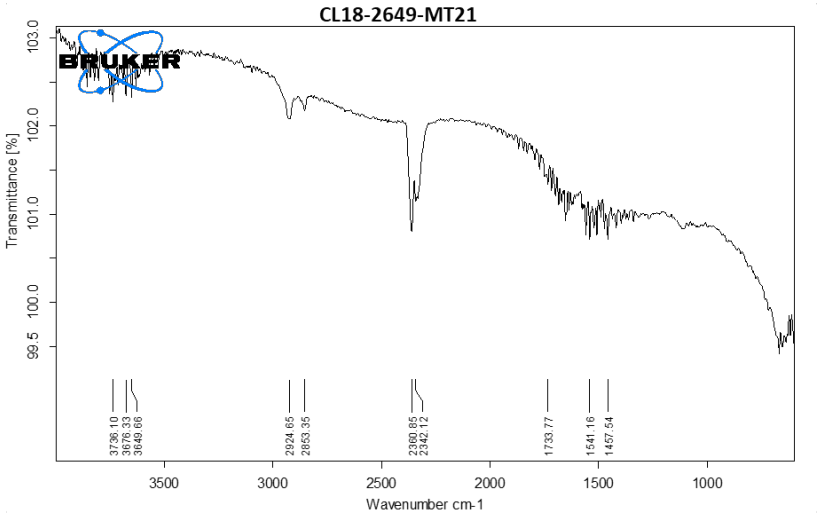

CL18-2624-MT16
BRUKER
Transmittance [%]
99.0
98.5
98.0
97.5
2957.48
2924.12
2854.05
2777.74
1648.72
1572.81
1458.14
1355.19
1340.72
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

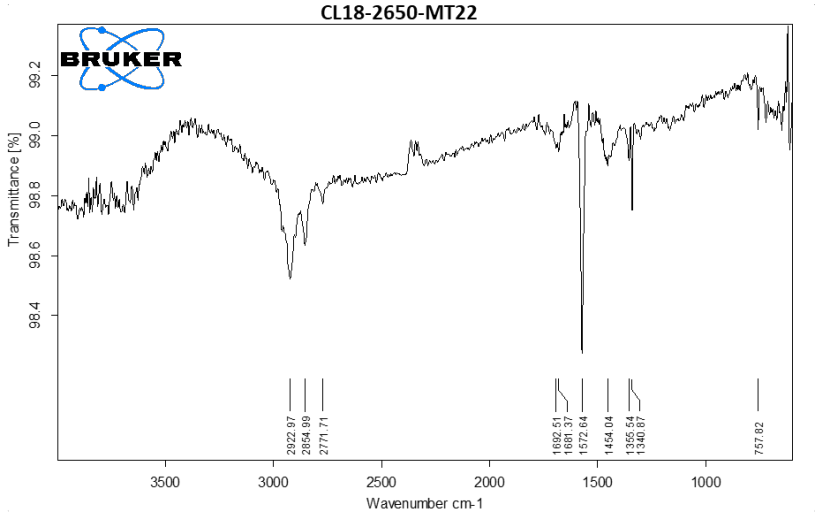

CL18-2625-MT17
BRUKER
Transmittance [%]
99.0
98.8
98.6
98.4
98.2
2923.99
2852.57
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

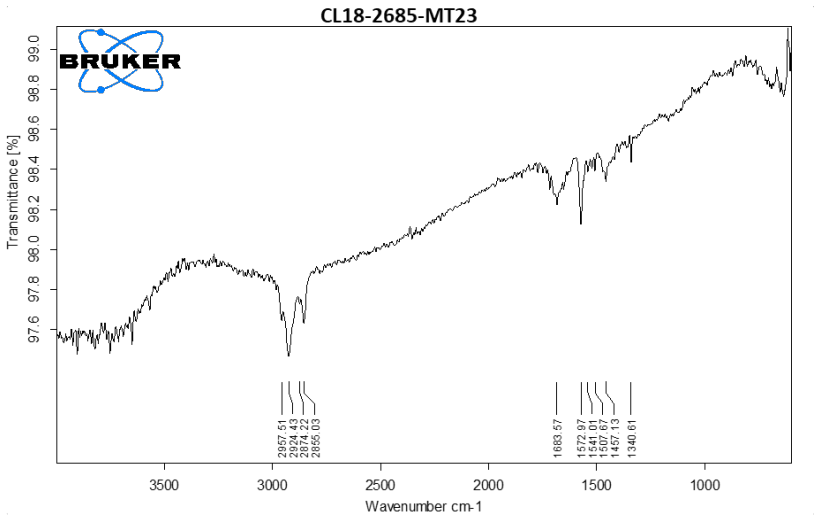

CL18-2638-MT18
BRUKER
Transmittance [%]
100.4
100.2
100.0
99.8
99.6
99.4
1572.88
1355.25
1340.95
756.03
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

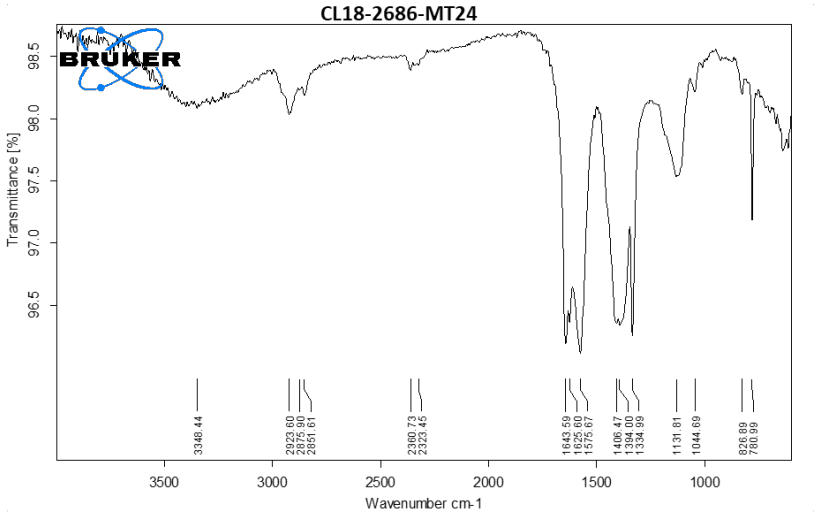

CL18-2647-MT19
BRUKER
Transmittance [%]
101.5
101.0
100.5
100.0
2357.95
2341.66
1599.46
1584.55
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

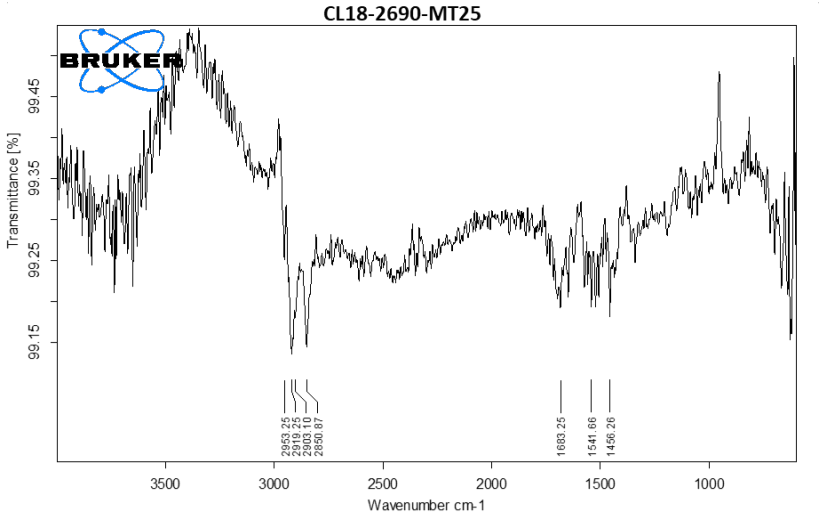

CL18-2648-MT20
BRUKER
Transmittance [%]
101.0
100.5
100.0
99.5
3826.51
3735.63
1647.65
1558.32
1541.11
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

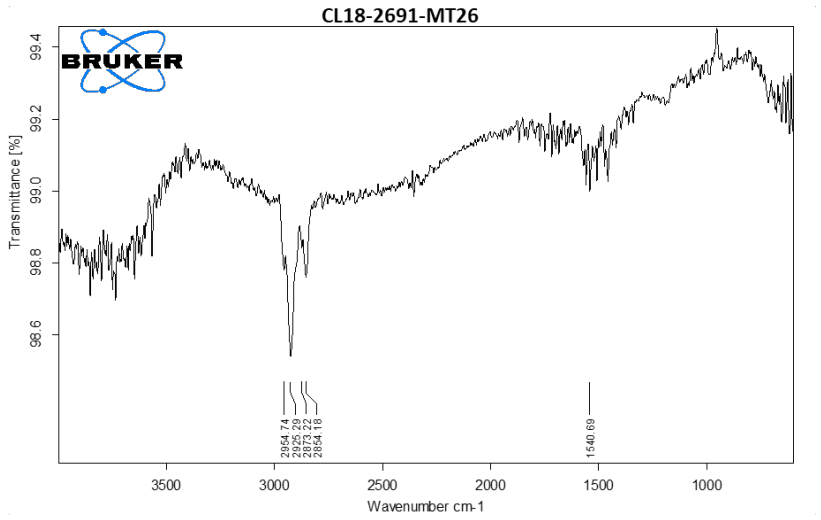

CL18-2649-MT21
BRUKER
Transmittance [%]
103.0
102.0
101.0
100.0
99.5
3736.10
3676.33
3649.66
2924.65
2853.35
2360.85
2342.12
1733.77
1541.16
1457.54
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

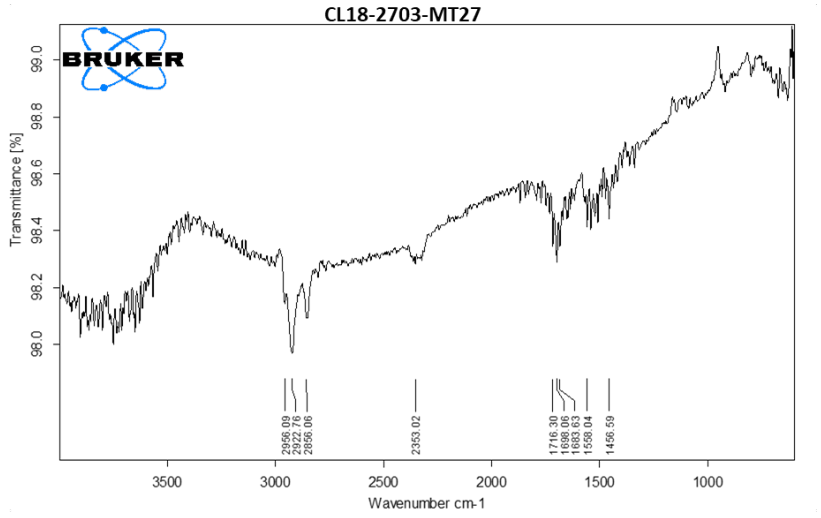

CL18-2650-MT22
BRUKER
Transmittance [%]
99.2
99.0
98.8
98.6
98.4
2922.97
2854.99
2771.71
1692.51
1681.37
1572.64
1454.04
1355.54
1340.87
757.82
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

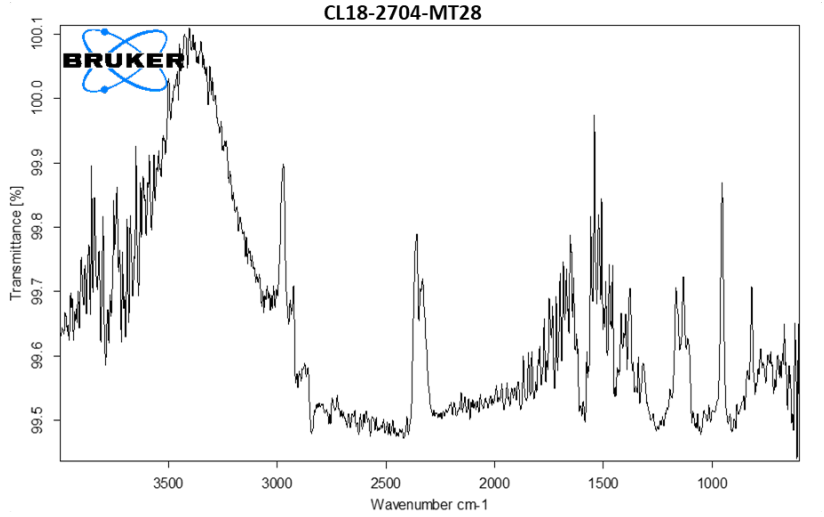

CL18-2685-MT23
BRUKER
Transmittance [%]
99.0
98.8
98.6
98.4
98.2
98.0
97.8
97.6
2957.51
2924.43
2874.22
2855.03
1683.57
1572.97
1541.67
1507.07
1457.13
1340.61
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

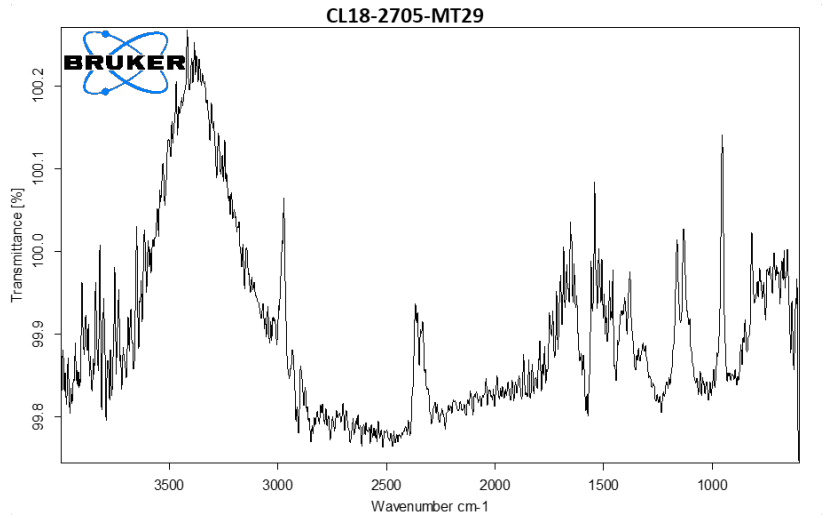

CL18-2686-MT24
BRUKER
Transmittance [%]
98.5
98.0
97.5
97.0
96.5
3348.44
2923.60
2875.90
2851.61
2360.73
2323.45
1643.59
1575.67
1406.47
1394.00
1334.99
1131.61
1044.69
826.89
780.99
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

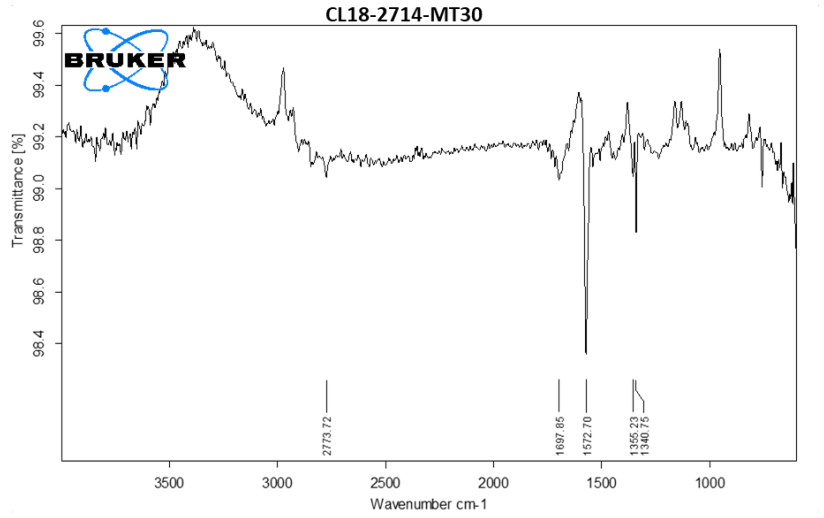

CL18-2690-MT25
BRUKER
Transmittance [%]
99.45
99.35
99.25
99.15
2953.25
2919.25
2903.10
2850.87
1683.25
1541.66
1456.26
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

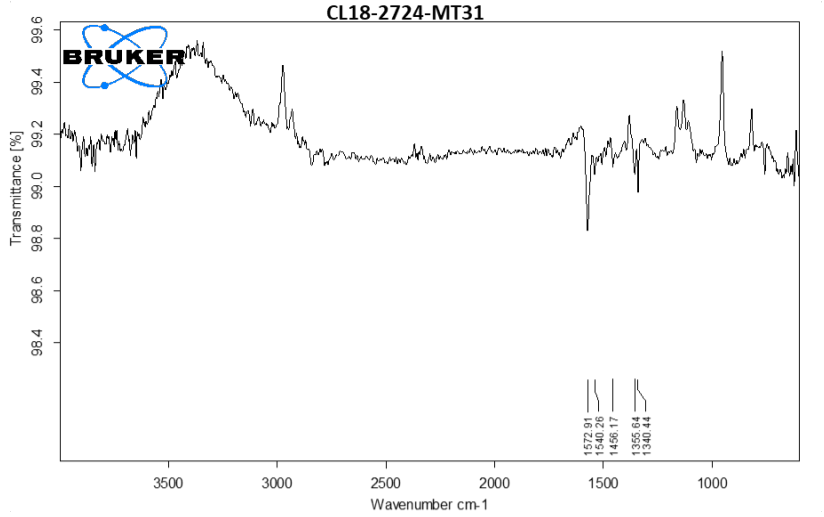

CL18-2691-MT26
BRUKER
Transmittance [%]
99.4
99.2
99.0
98.8
98.6
2954.74
2925.29
2873.22
2854.18
1540.69
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

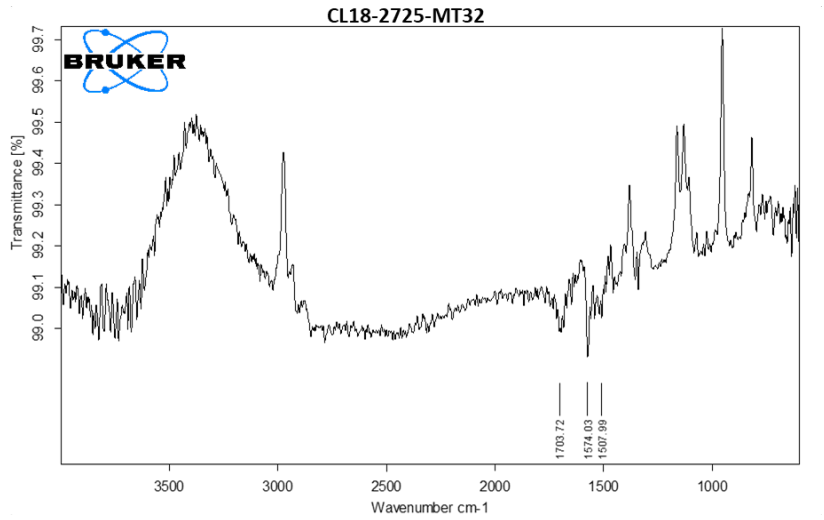

CL18-2703-MT27
BRUKER
Transmittance [%]
99.0
98.8
98.6
98.4
98.2
98.0
2956.09
2922.76
2856.06
2353.02
1716.30
1698.95
1683.63
1558.04
1456.59
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

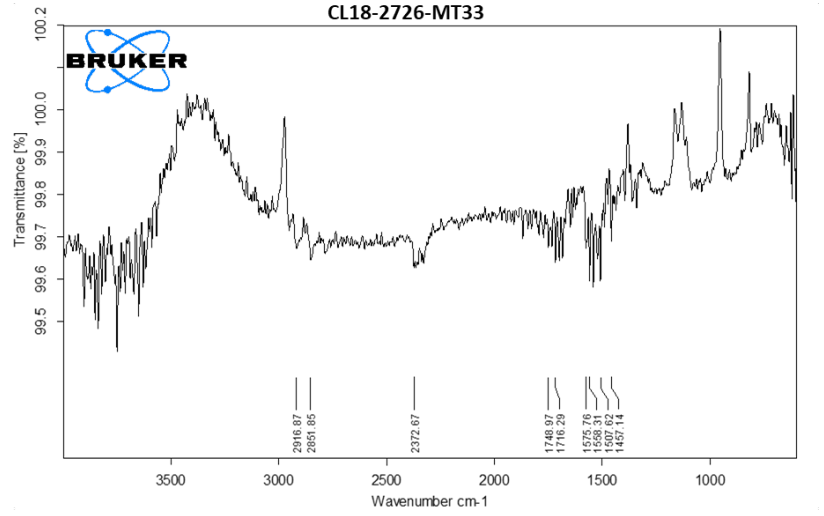

CL18-2704-MT28
BRUKER
Transmittance [%]
100.1
100.0
99.9
99.8
99.7
99.6
99.5
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

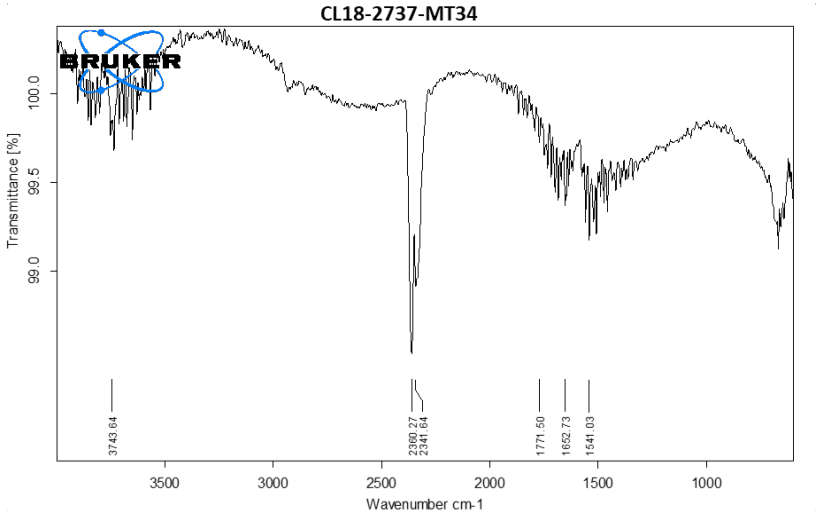

CL18-2705-MT29
BRUKER
Transmittance [%]
100.2
100.1
100.0
99.9
99.8
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

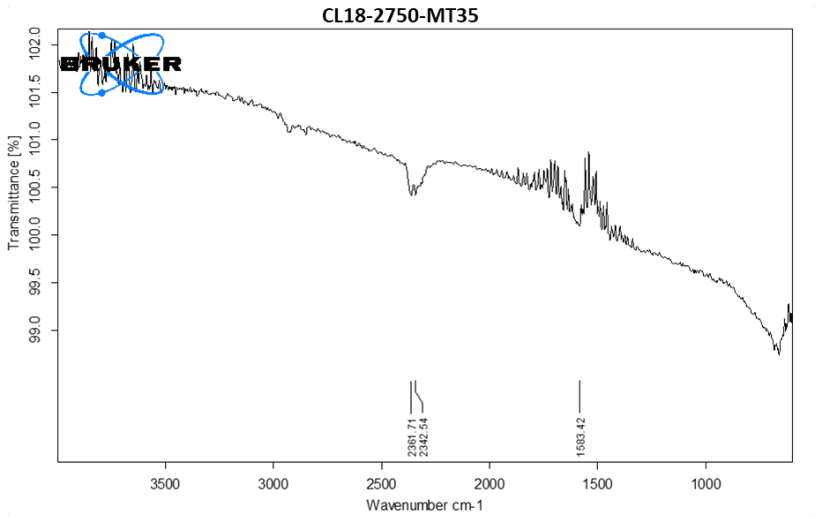

CL18-2714-MT30
BRUKER
Transmittance [%]
99.6
99.4
99.2
99.0
98.8
98.6
98.4
2773.72
1697.85
1572.70
1355.23
1340.75
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

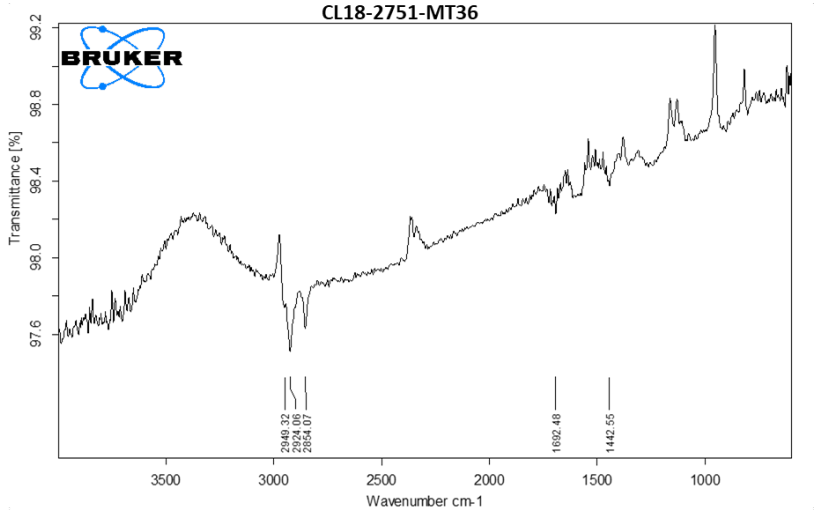

CL18-2724-MT31
BRUKER
Transmittance [%]
99.6
99.4
99.2
99.0
98.8
98.6
98.4
1572.91
1540.26
1456.17
1355.64
1340.44
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

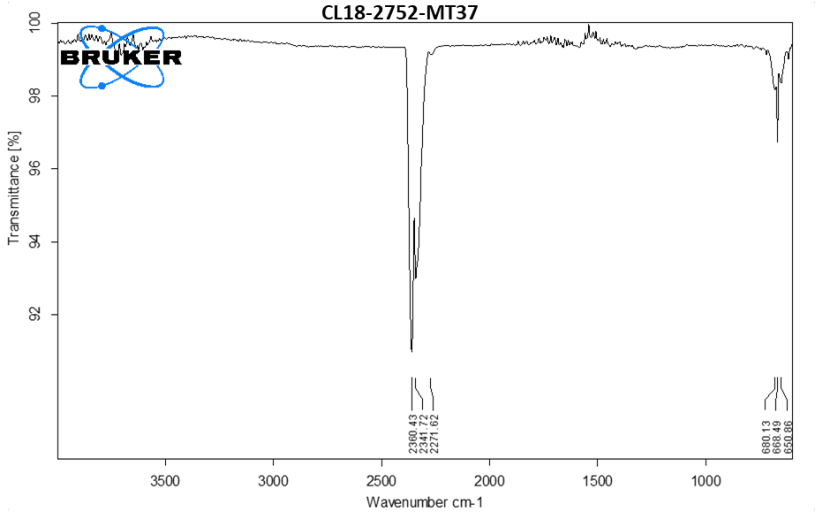

CL18-2725-MT32
BRUKER
Transmittance [%]
99.7
99.6
99.5
99.4
99.3
99.2
99.1
99.0
1703.72
1574.03
1507.99
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

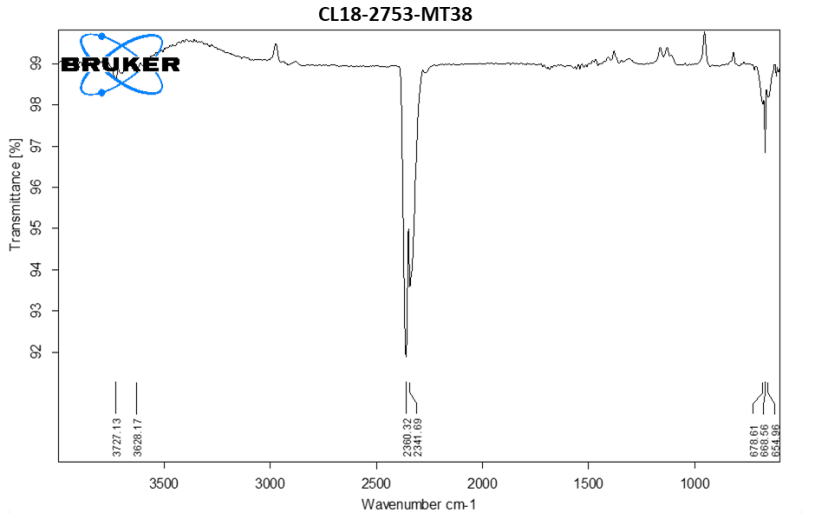

CL18-2726-MT33
BRUKER
Transmittance [%]
100.2
100.0
99.9
99.8
99.7
99.6
99.5
2916.87
2851.85
2372.67
1748.97
1716.29
1575.76
1538.31
1507.82
1457.14
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

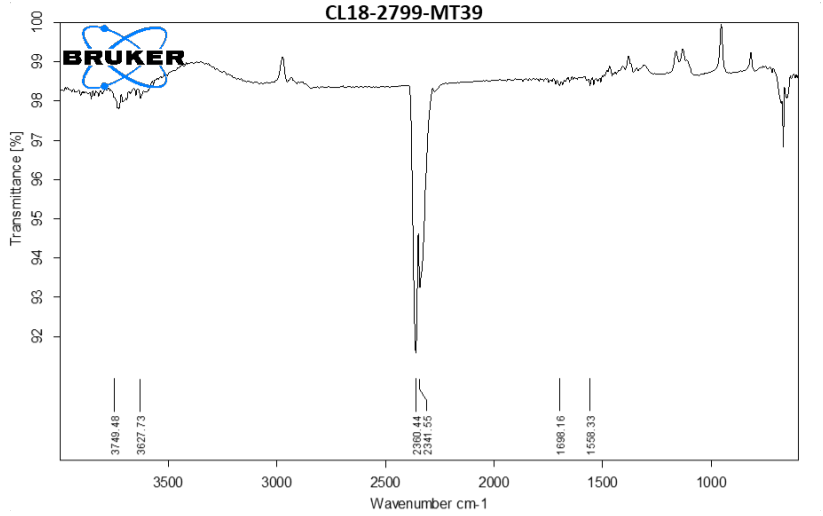

CL18-2737-MT34
BRUKER
Transmittance [%]
100.0
99.5
99.0
3743.64
2360.27
2341.64
1771.50
1652.73
1541.03
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

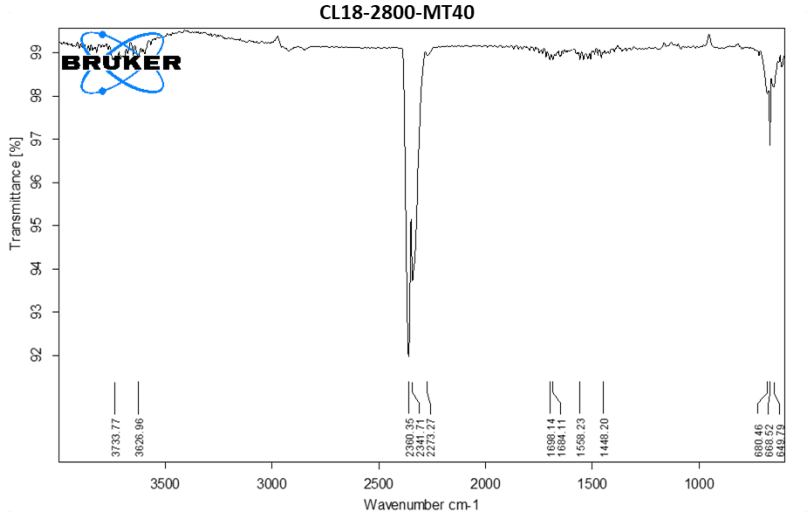

CL18-2750-MT35
BRUKER
Transmittance [%]
102.0
101.5
101.0
100.5
100.0
99.5
99.0
2361.71
2342.54
1583.42
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

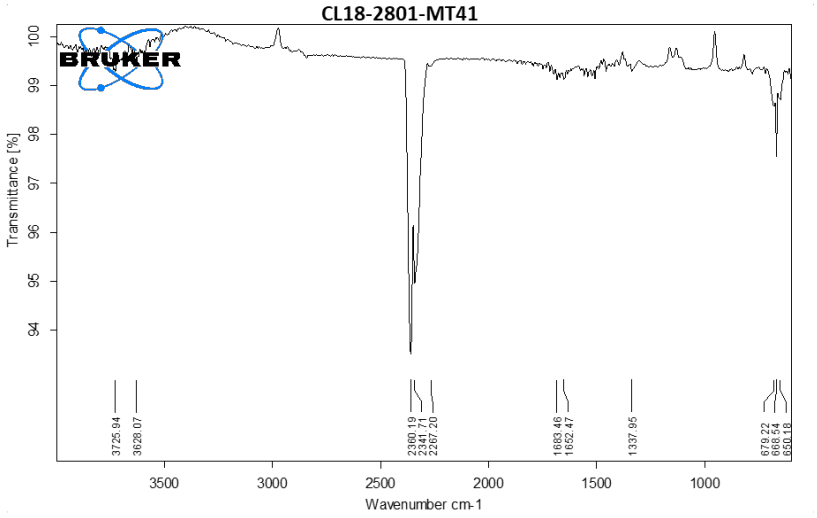

CL18-2751-MT36
BRUKER
Transmittance [%]
99.2
98.8
98.4
98.0
97.6
2949.32
2924.06
2854.07
1692.48
1442.55
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

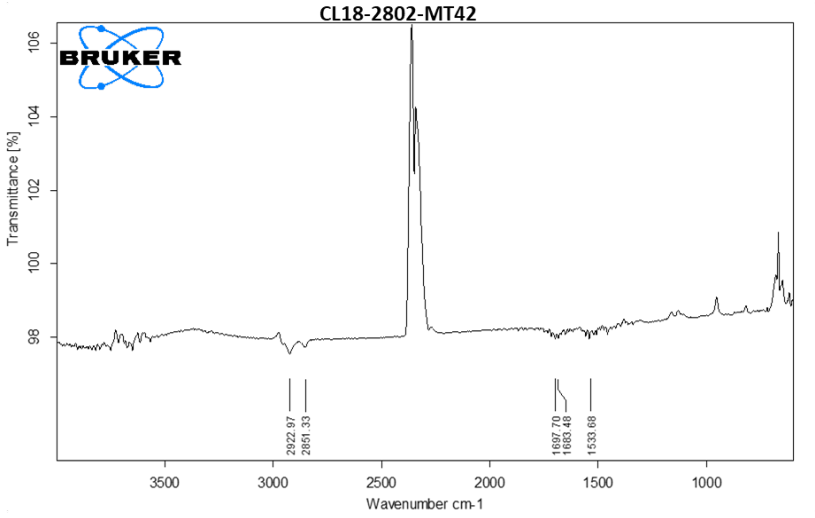

CL18-2752-MT37
BRUKER
Transmittance [%]
100
98
96
94
92
2360.43
2341.72
2271.62
680.13
668.49
650.88
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

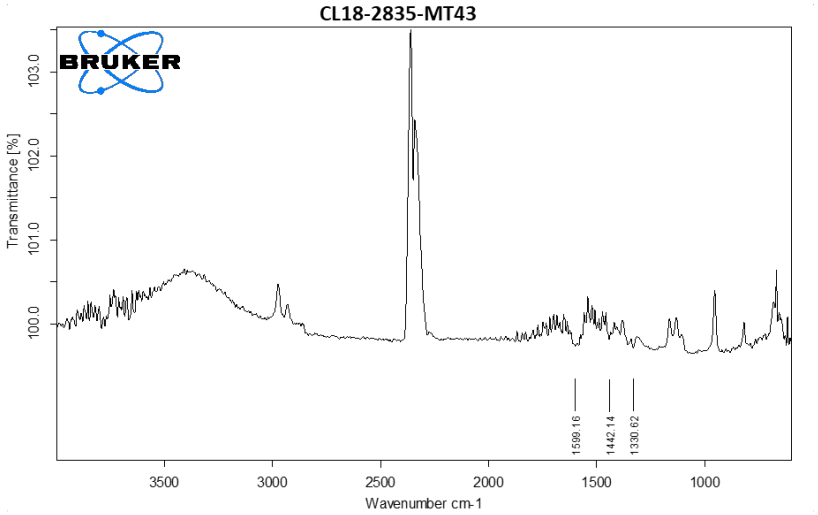

CL18-2753-MT38
BRUKER
Transmittance [%]
99
98
97
96
95
94
93
92
3727.13
3628.17
2360.32
2341.69
678.61
668.56
654.96
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

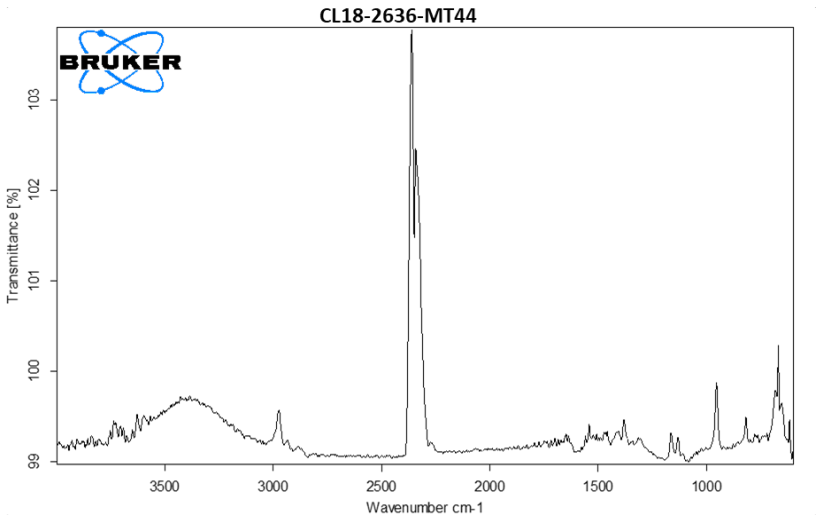

CL18-2799-MT39
BRUKER
Transmittance [%]
100
99
98
97
96
95
94
93
92
3749.48
3627.73
2360.44
2341.55
1698.16
1558.33
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

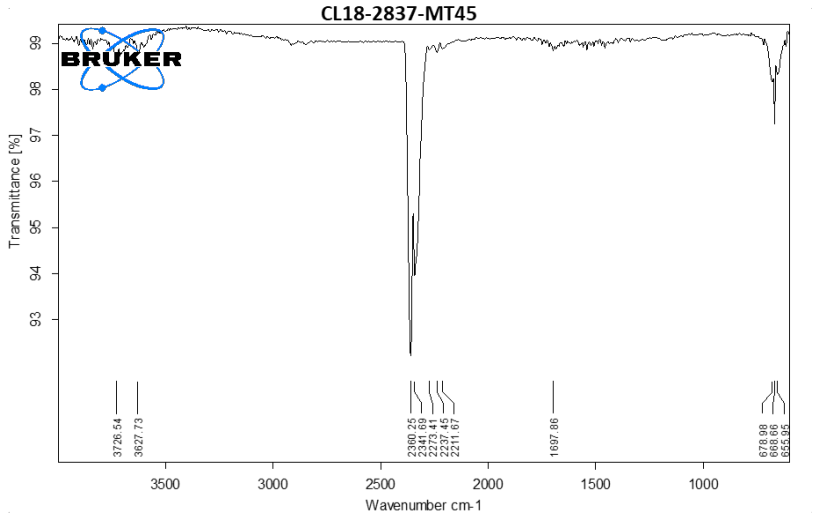

CL18-2800-MT40
BRUKER
Transmittance [%]
99
98
97
96
95
94
93
92
3733.77
3626.96
2360.35
2341.71
2273.27
1688.14
1684.11
1558.23
1448.20
680.46
668.42
649.79
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

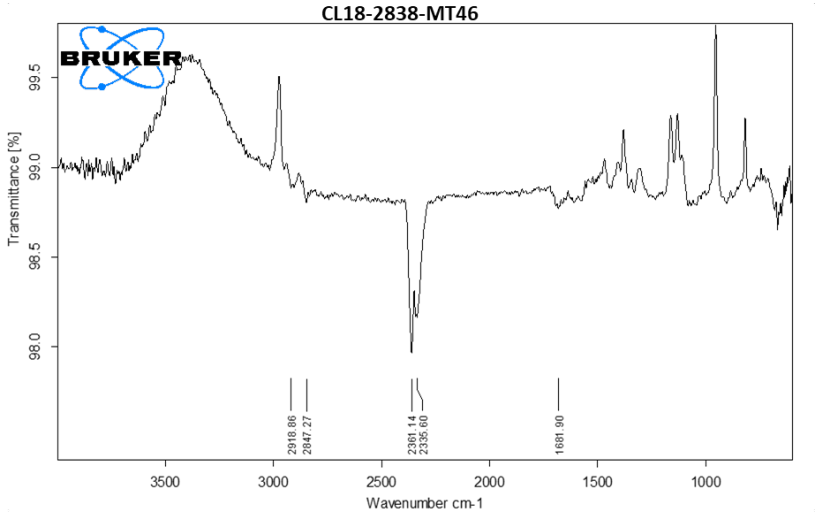

CL18-2801-MT41
BRUKER
Transmittance [%]
100
99
98
97
96
95
94
3725.94
3628.07
2360.19
2341.71
2267.20
1683.46
1652.47
1337.95
679.22
668.54
658.18
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

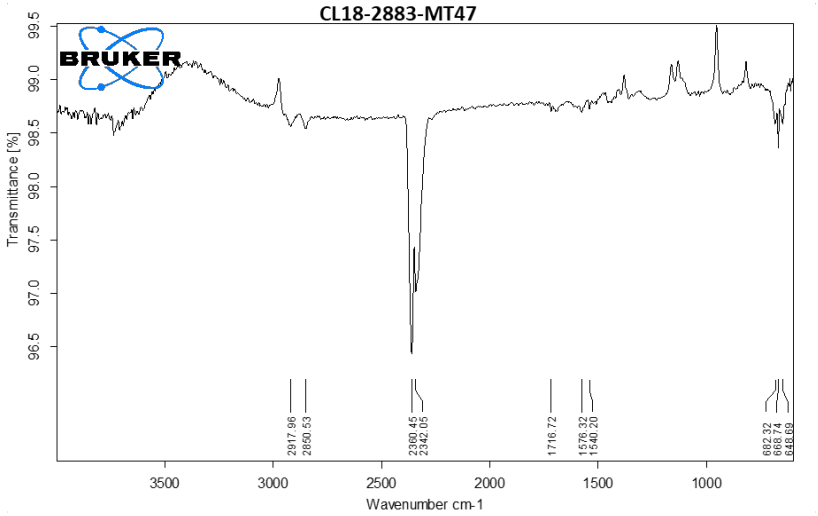

CL18-2802-MT42
BRUKER
Transmittance [%]
106
104
102
100
98
2922.97
2851.33
1697.70
1683.48
1533.68
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

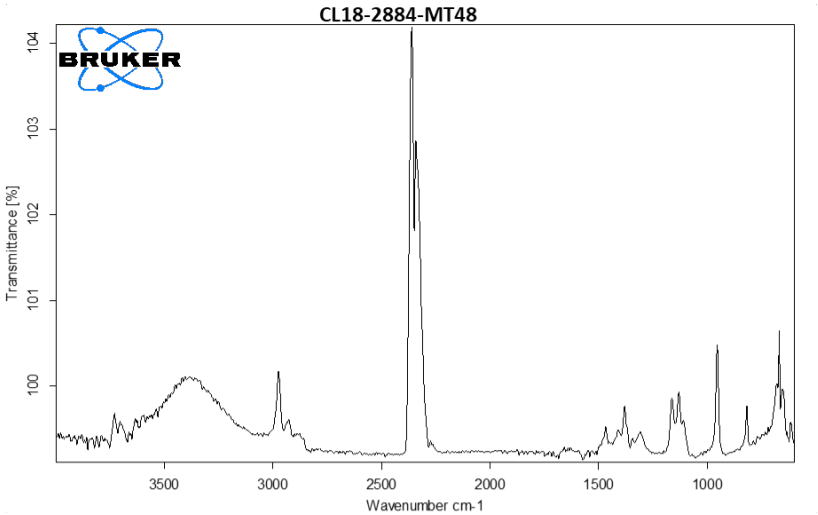

CL18-2835-MT43
BRUKER
Transmittance [%]
103.0
102.0
101.0
100.0
1599.16
1442.14
1330.62
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

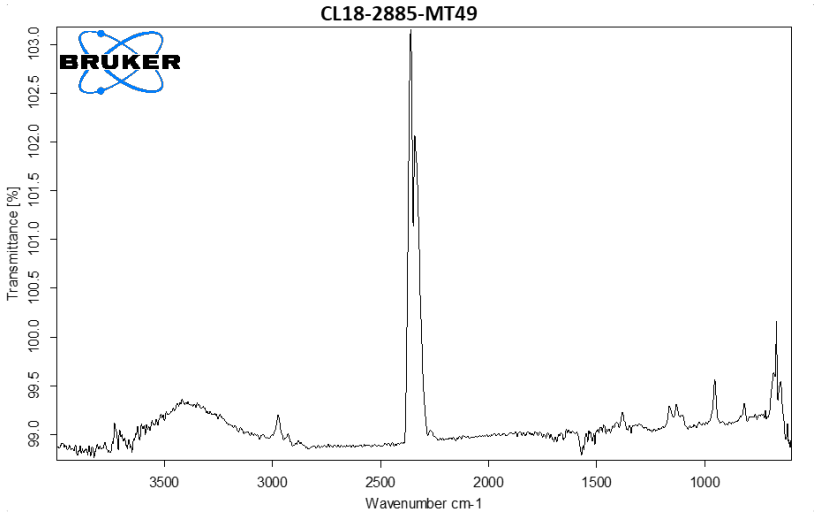

CL18-2636-MT44
BRUKER
Transmittance [%]
103
102
101
100
99
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

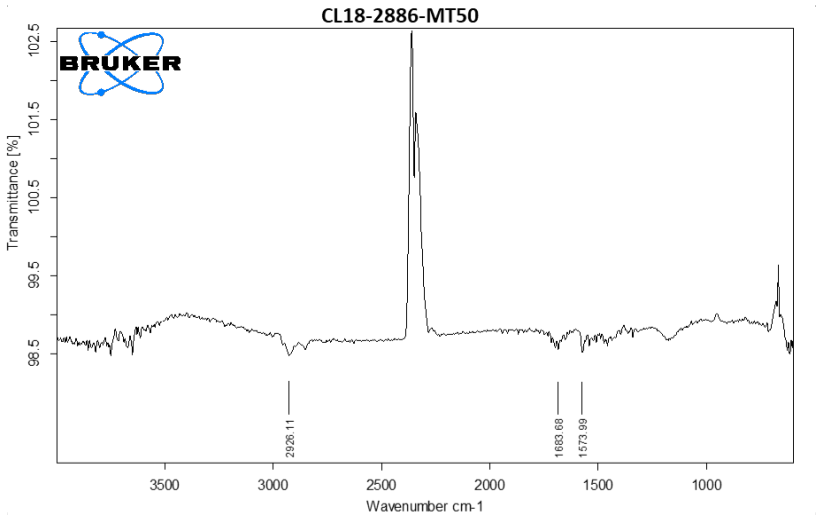

CL18-2837-MT45
BRUKER
Transmittance [%]
99
98
97
96
95
94
93
3726.54
3627.73
2300.25
2345.69
2273.41
2237.45
2211.67
1697.86
678.98
668.65
655.95
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

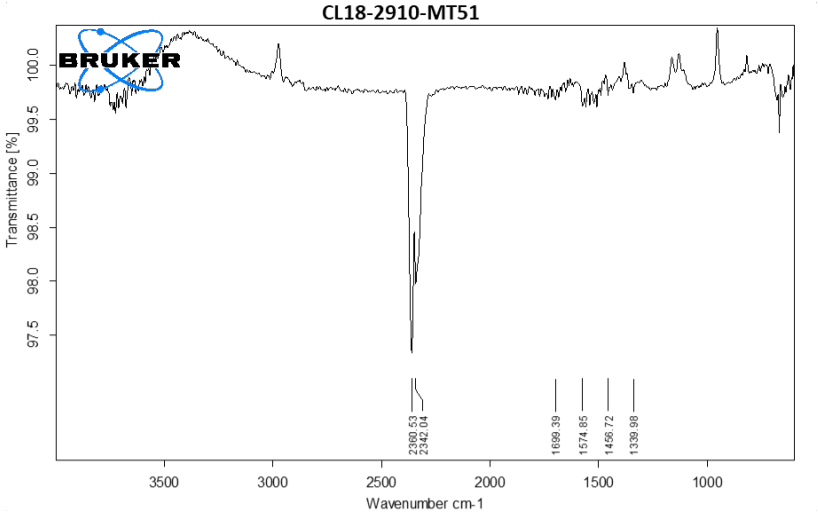

CL18-2838-MT46
BRUKER
Transmittance [%]
99.5
99.0
98.5
98.0
2918.86
2847.27
2361.14
2335.60
1681.90
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

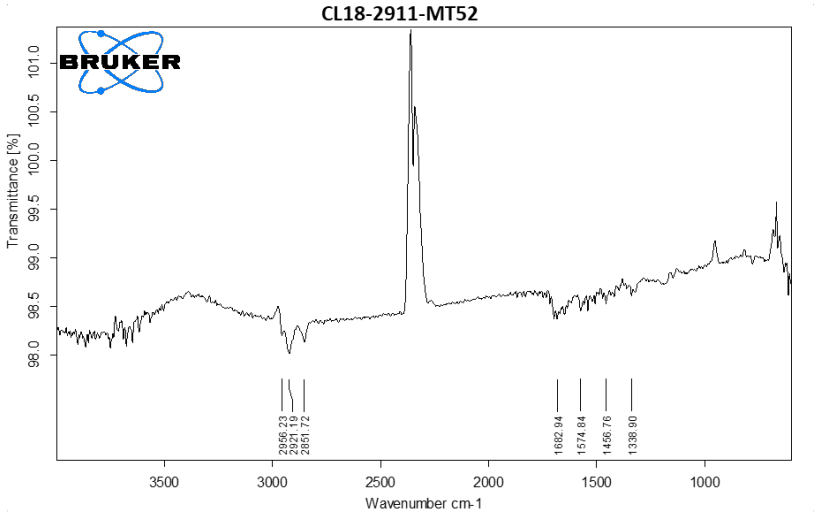

CL18-2883-MT47
BRUKER
Transmittance [%]
99.5
99.0
98.5
98.0
97.5
97.0
96.5
2917.96
2850.53
2360.45
2342.05
1716.72
1578.32
1540.20
682.32
668.74
648.09
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

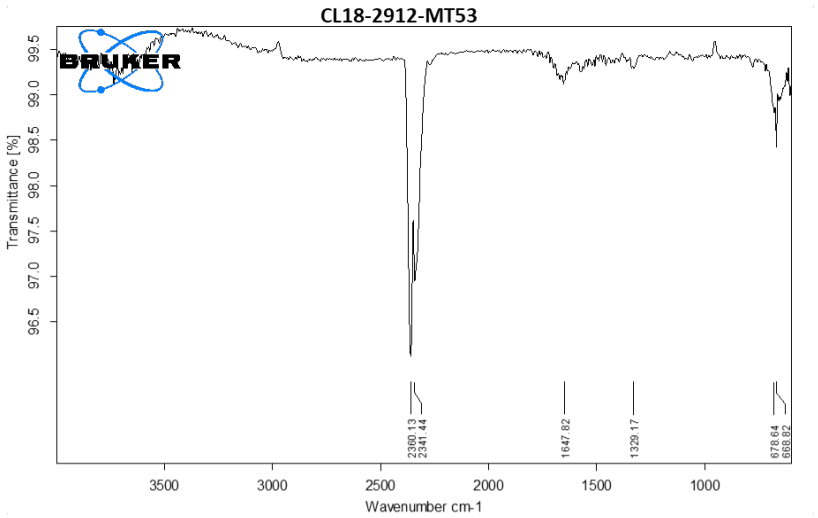

CL18-2884-MT48
BRUKER
Transmittance [%]
104
103
102
101
100
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

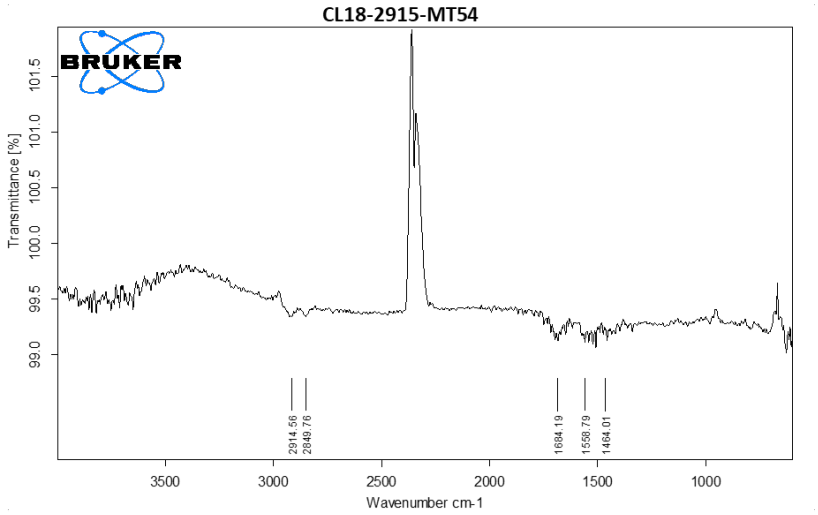

CL18-2885-MT49
BRUKER
Transmittance [%]
103.0
102.5
102.0
101.5
101.0
100.5
100.0
99.5
99.0
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

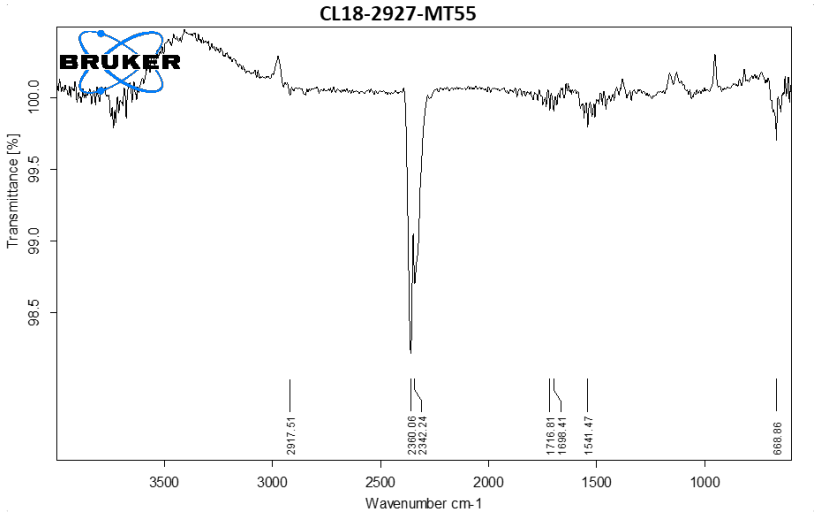

CL18-2886-MT50
BRUKER
Transmittance [%]
102.5
101.5
100.5
99.5
98.5
2926.11
1683.68
1573.99
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

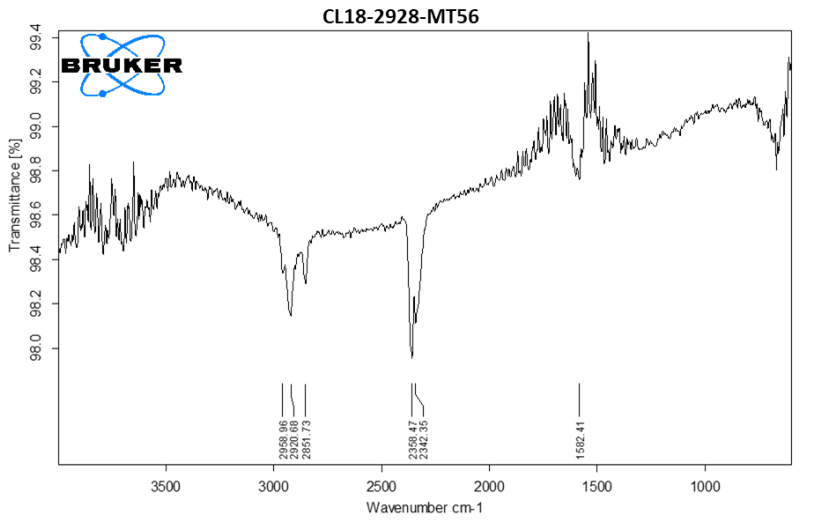

CL18-2910-MT51
BRUKER
Transmittance [%]
100.0
99.5
99.0
98.5
98.0
97.5
2360.53
2342.04
1689.39
1574.85
1456.72
1339.98
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

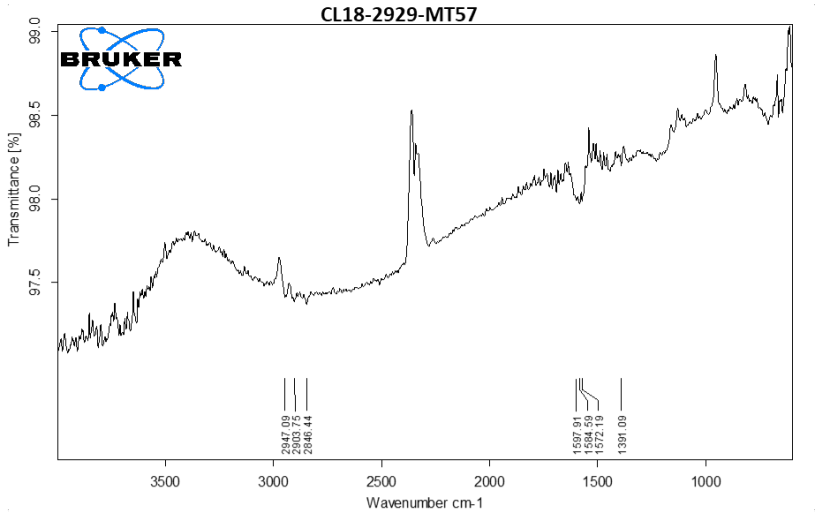

CL18-2911-MT52
BRUKER
Transmittance [%]
101.0
100.5
100.0
99.5
99.0
98.5
98.0
2956.23
2921.19
2851.72
1682.94
1574.84
1456.76
1338.90
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

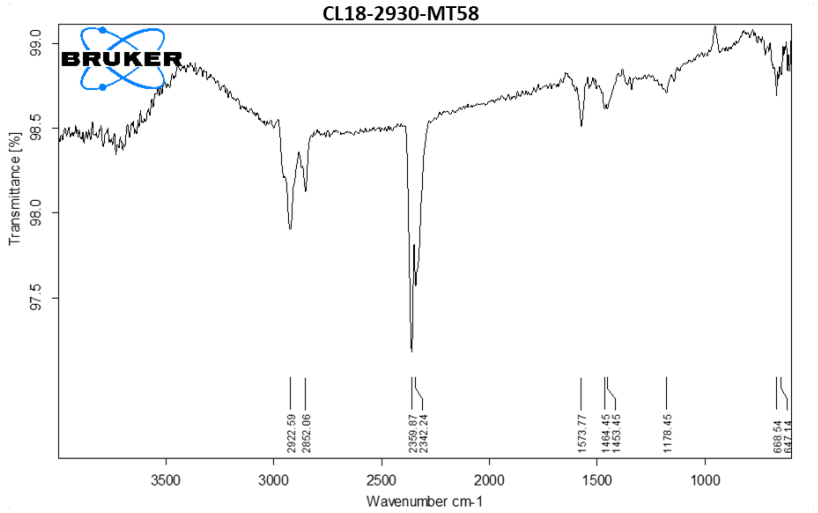

CL18-2912-MT53
BRUKER
Transmittance [%]
99.5
99.0
98.5
98.0
97.5
97.0
96.5
2360.13
2341.44
1647.82
1329.17
678.64
668.82
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

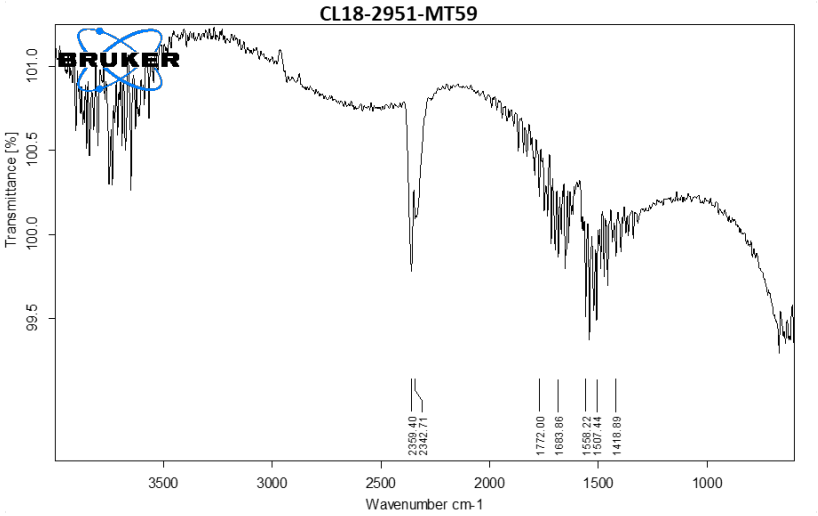

CL18-2915-MT54
BRUKER
Transmittance [%]
101.5
101.0
100.5
100.0
99.5
99.0
2914.56
2849.76
1684.19
1558.79
1464.01
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

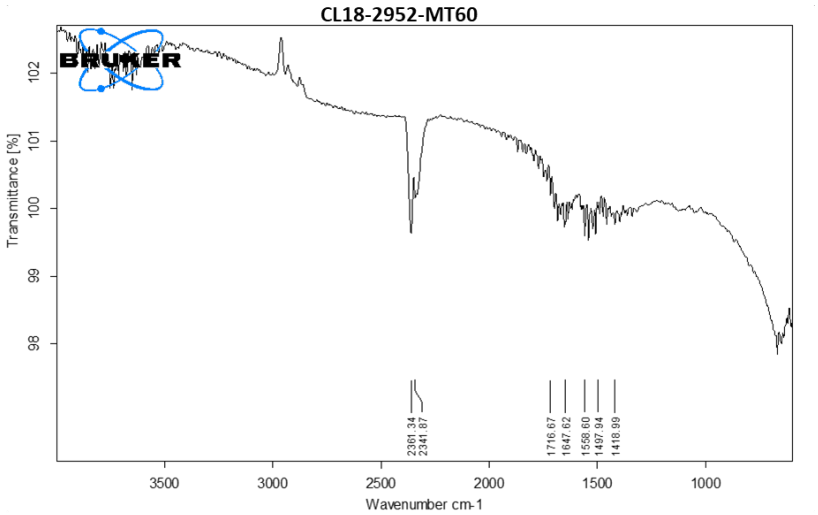

CL18-2927-MT55
BRUKER
Transmittance [%]
100.0
99.5
99.0
98.5
2917.51
2360.06
2342.24
1716.81
1698.41
1541.47
668.86
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

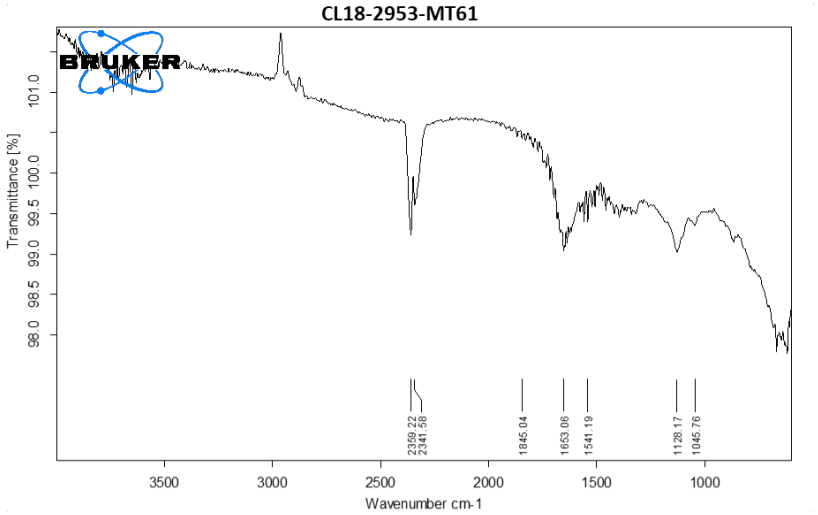

CL18-2928-MT56
BRUKER
Transmittance [%]
99.4
99.2
99.0
98.8
98.6
98.4
98.2
98.0
2958.96
2920.68
2851.73
2358.47
2342.35
1582.41
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

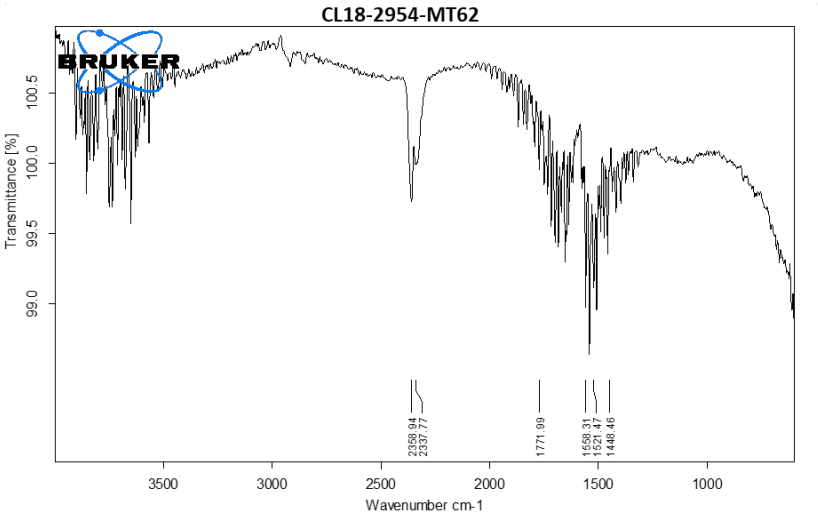

CL18-2929-MT57
BRUKER
Transmittance [%]
99.0
98.5
98.0
97.5
2947.09
2903.75
2846.44
1597.91
1584.59
1572.19
1391.09
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

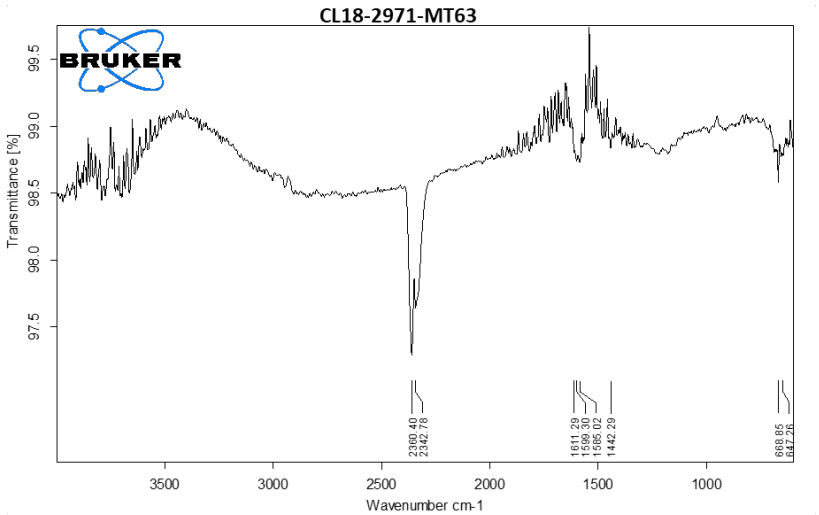

CL18-2930-MT58
BRUKER
Transmittance [%]
99.0
98.5
98.0
97.5
2922.59
2852.06
2359.87
2342.24
1573.77
1464.45
1453.45
1178.45
668.54
647.14
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

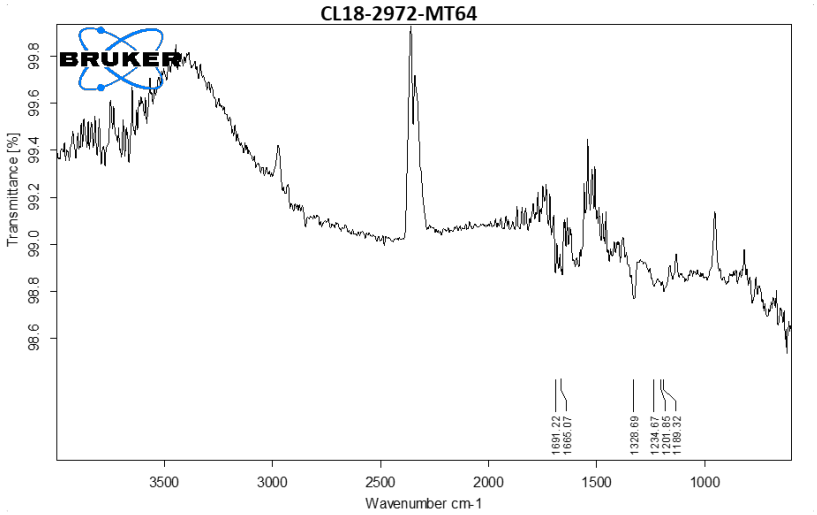

CL18-2951-MT59
BRUKER
Transmittance [%]
101.0
100.5
100.0
99.5
2359.40
2342.71
1772.00
1683.86
1558.22
1507.44
1418.89
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

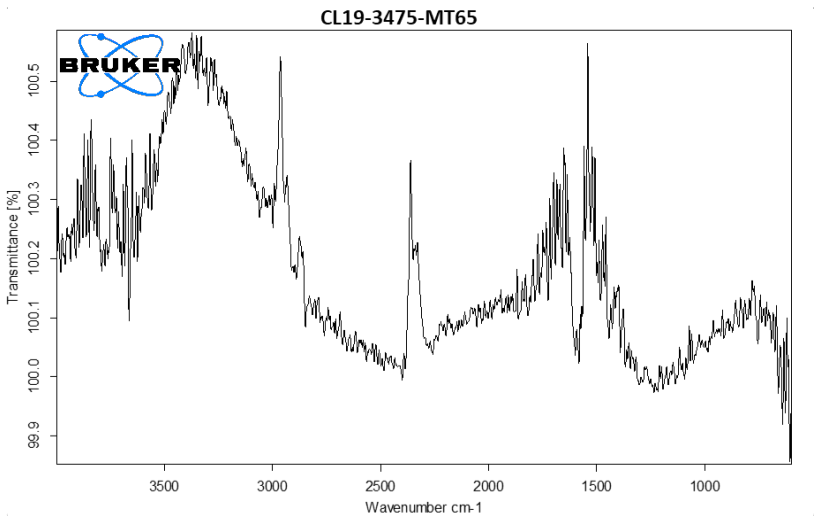

CL18-2952-MT60
BRUKER
Transmittance [%]
102
101
100
99
98
2361.34
2341.87
1716.67
1647.62
1558.60
1497.94
1418.99
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

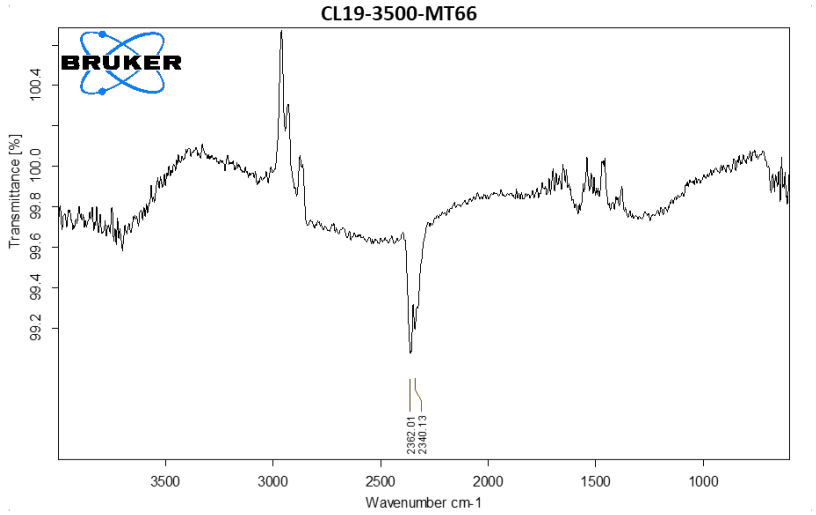

CL18-2953-MT61
BRUKER
Transmittance [%]
101.0
100.0
99.5
99.0
98.5
98.0
2359.22
2341.58
1845.04
1653.06
1541.19
1128.17
1045.76
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

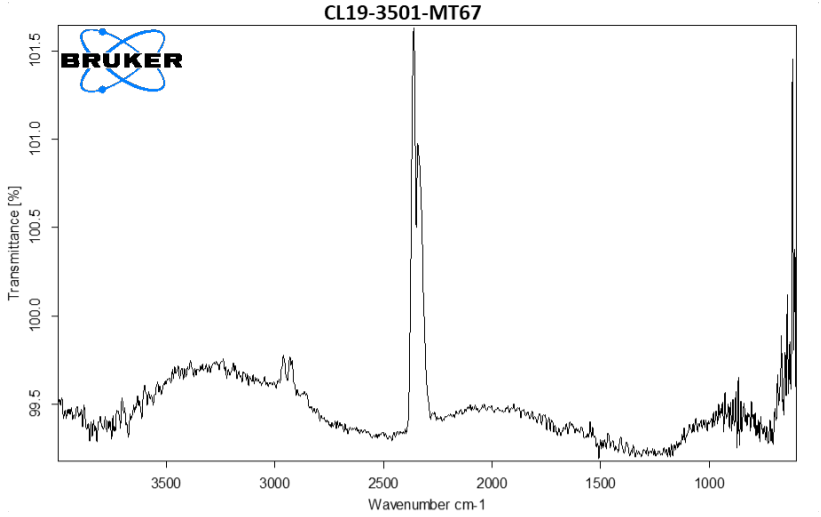

CL18-2954-MT62
BRUKER
Transmittance [%]
100.5
100.0
99.5
99.0
2358.94
2337.77
1771.99
1558.31
1521.47
1448.46
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

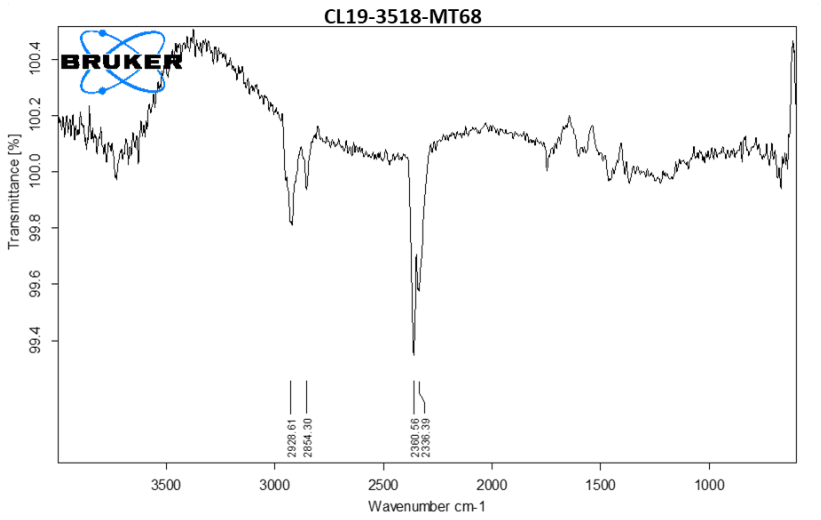

CL18-2971-MT63
BRUKER
Transmittance [%]
99.5
99.0
98.5
98.0
97.5
2360.40
2342.78
1611.29
1598.30
1586.02
1442.29
668.85
647.26
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

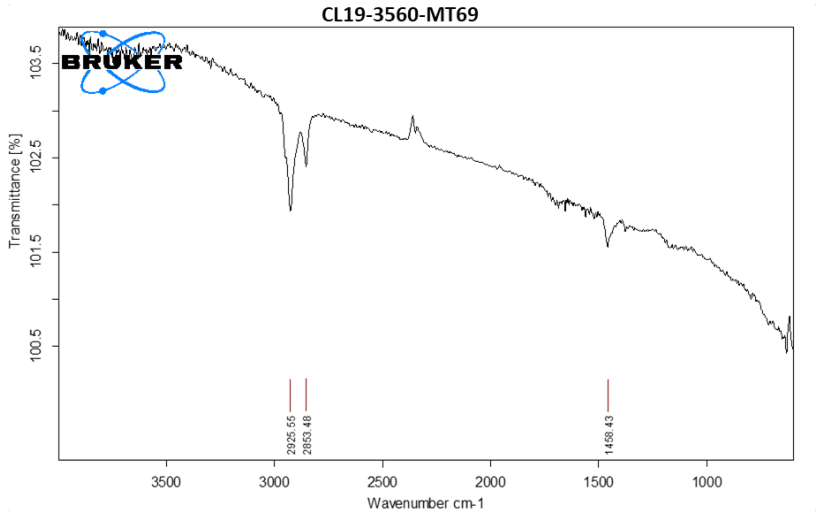

CL18-2972-MT64
BRUKER
Transmittance [%]
99.8
99.6
99.4
99.2
99.0
98.8
98.6
1691.22
1665.07
1328.69
1234.67
1201.85
1169.32
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

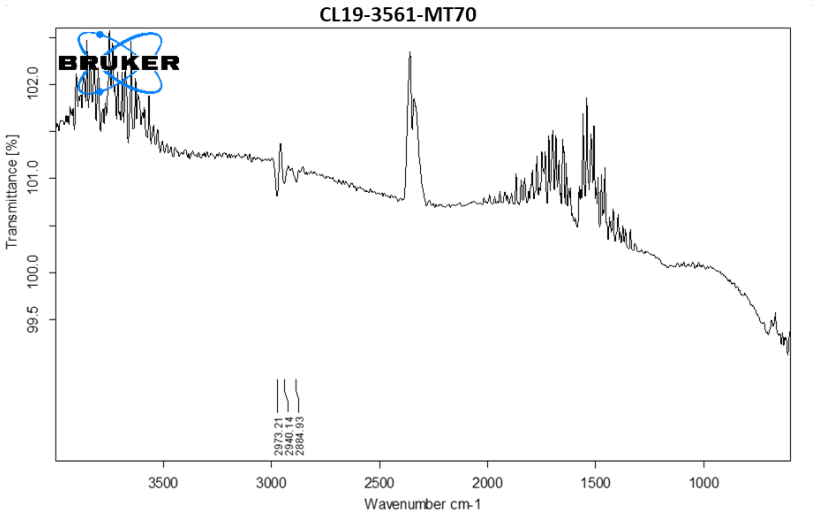

CL19-3475-MT65
BRUKER
Transmittance [%]
100.5
100.4
100.3
100.2
100.1
100.0
99.9
3500
3000
2500
2000
1500
1000
Wavenumber cm-1


CL19-3500-MT66
BRUKER
Transmittance [%]
100.4
100.0
99.8
99.6
99.4
99.2
2362.01
2340.13
3500
3000
2500
2000
1500
1000
Wavenumber cm-1


CL19-3501-MT67
BRUKER
Transmittance [%]
101.5
101.0
100.5
100.0
99.5
3500
3000
2500
2000
1500
1000
Wavenumber cm-1


CL19-3518-MT68
BRUKER
Transmittance [%]
100.4
100.2
100.0
99.8
99.6
99.4
2928.61
2854.30
2360.56
2336.39
3500
3000
2500
2000
1500
1000
Wavenumber cm-1


CL19-3560-MT69
BRUKER
Transmittance [%]
103.5
102.5
101.5
100.5
2925.55
2853.48
1458.43
3500
3000
2500
2000
1500
1000
Wavenumber cm-1


CL19-3561-MT70
BRUKER
Transmittance [%]
102.0
101.0
100.0
99.5
2973.21
2940.14
2884.93
3500
3000
2500
2000
1500
1000
Wavenumber cm-1

APPENDIX D

INJECTOR PINTLE PHOTOGRAPHS

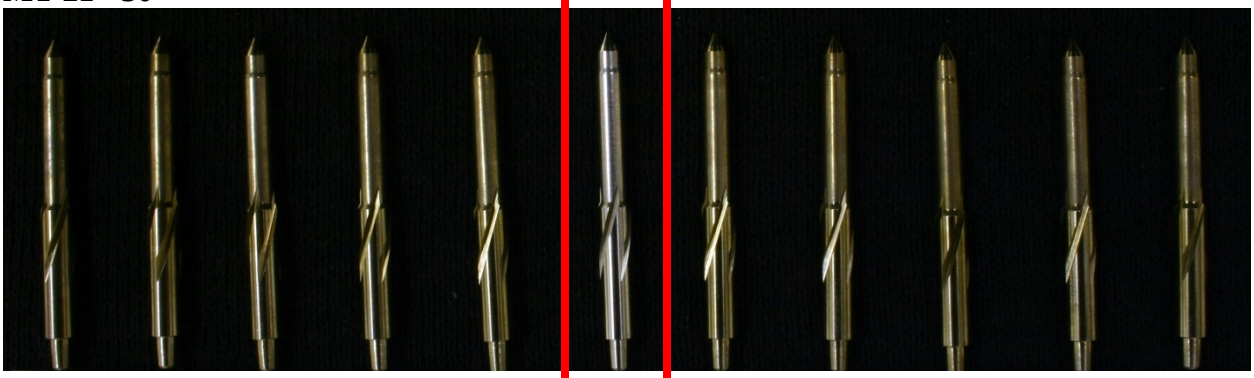
On the following two pages are the combined photographs of all the pintles used in the matrix program. Each photograph contains ten (10) pintles from the matrix program, in numerical order, arranged around the untested, reference pintle.

With the centrally place reference pintle in each picture, it is obvious that the matrix pintles are used. What is not apparent is any obvious relationship between their appearance and their associated results in the matrix program.

MT 01 – 10 **REFERENCE**

MT 11 - 20

MT 21 - 30



MT 31 - 40

MT 41 – 50 **REFERENCE**

MT 51 - 60

MT 61 - 70

APPENDIX E

Statistical Analyses Conducted by Chevron

Fuel Research Using the Internal Diesel Injector Deposit (IDID) Rig (CRC Project No. DP-04-17) *Matrix Analysis*

Jo Martinez

Staff Statistician, Chevron

Dec. 4, 2018

Conclusions

Deposit by Location on Pintle

- No significant axial location differences
- No significant radial location differences

Deposit (average of 84 measurements)

- Sodium increases deposit thickness
- No significant Corrosion Inhibitor and Cetane Number Improver differences
- Detergent additive reduces deposit thickness in fuels without biodiesel
- Sodium increases deposit thickness in fuels without
  - Detergent additive
  - Mono acid lubricity additive
- Sodium increases deposit thickness more significantly in fuels without glycerin than with glycerin
- Conductivity additive increases deposit thickness in fuels without
  - Biodiesel
  - Glycerin
- Conductivity additive increases deposit thickness in fuels with mono acid lubricity additive

Summary of Interaction Effects

Without Detergent Additive	With Detergent Additive
- Sodium	- Sodium
Without Biodiesel	With Biodiesel
- Detergent Additive	- Detergent Additive
- Conductivity Additive	- Conductivity Additive
Without Glycerin	With Glycerin
- Sodium (significant)	- Sodium (marginal)
- Conductivity Additive	- Conductivity Additive
Without Mono Acid Lubricity Additive	With Mono Acid Lubricity Additive
- Sodium	- Sodium
- Conductivity Additive	- Conductivity Additive

- Interaction effects color legend:
  - Green (reduces deposit thickness)
  - Red (increases deposit thickness)
  - Black (differences are not statistically significant, neutral)

Matrix Design

- **Fractional Factorial Design:** 2^{8-2} = 64 tests

- **Factors (Levels):**
  - Biodiesel (No, Yes)
  - Sodium (No, Yes)
  - Glycerin (No, Yes)
  - Corrosion Inhibitor (No, Yes)
  - Mono Acid Lubricity Additive (No, Yes)
  - Detergent Additive (No, Yes)
  - Cetane Number Improver (No, Yes)
  - Conductivity Additive (No, Yes)

- **Response:** Deposit Thickness, nm

- **Objective:** Determine factors affecting Deposit Thickness

Deposit Thickness Data

- Repeated Measurements per matrix test
  - Axial Location: 21
  - Radial Location: 4
  - Total measurements per test: 84

- Analyses performed on the following deposit thickness responses:
  - Deposit (Average of all 84 measurements per test)
  - Ri, i=1 to 4 (Average of 21 measurements per radial location)
  - Aj, j=1 to 21 (Average of 4 measurements per axial location)
  - Slope (Slope of the estimated linear equation from A1 to A21)
  - Deposit_Axial (Average of 4 radial measurements per axial location)
    - To determine differences in axial location
  - Deposit_Radial (Average of 21 axial measurements per radial location)
    - To determine differences in radial location

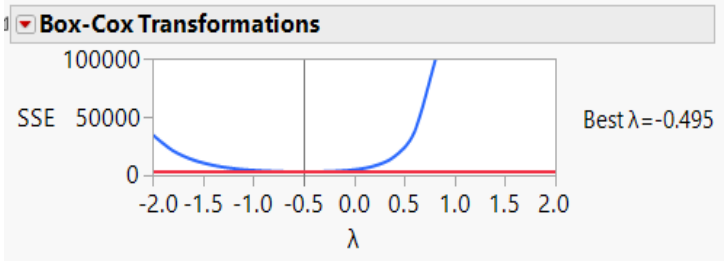
Analysis of Variance (ANOVA)

- Modeled 64 deposit thickness data
- **Inverse square root** transformation was applied to the deposit thickness data
- Regressed **transformed deposit thickness data** on:
  - Main effects (8)
  - Two-factor interaction effects (28)

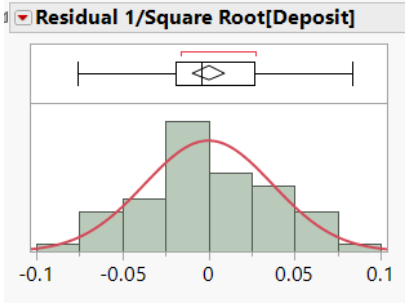
Transformation of Deposit Thickness

- Since ANOVA is based on the assumption that the model residuals (difference between actual and model predicted values) come from a Normal distribution, often times a transformation is needed to ensure that this assumption is not violated.

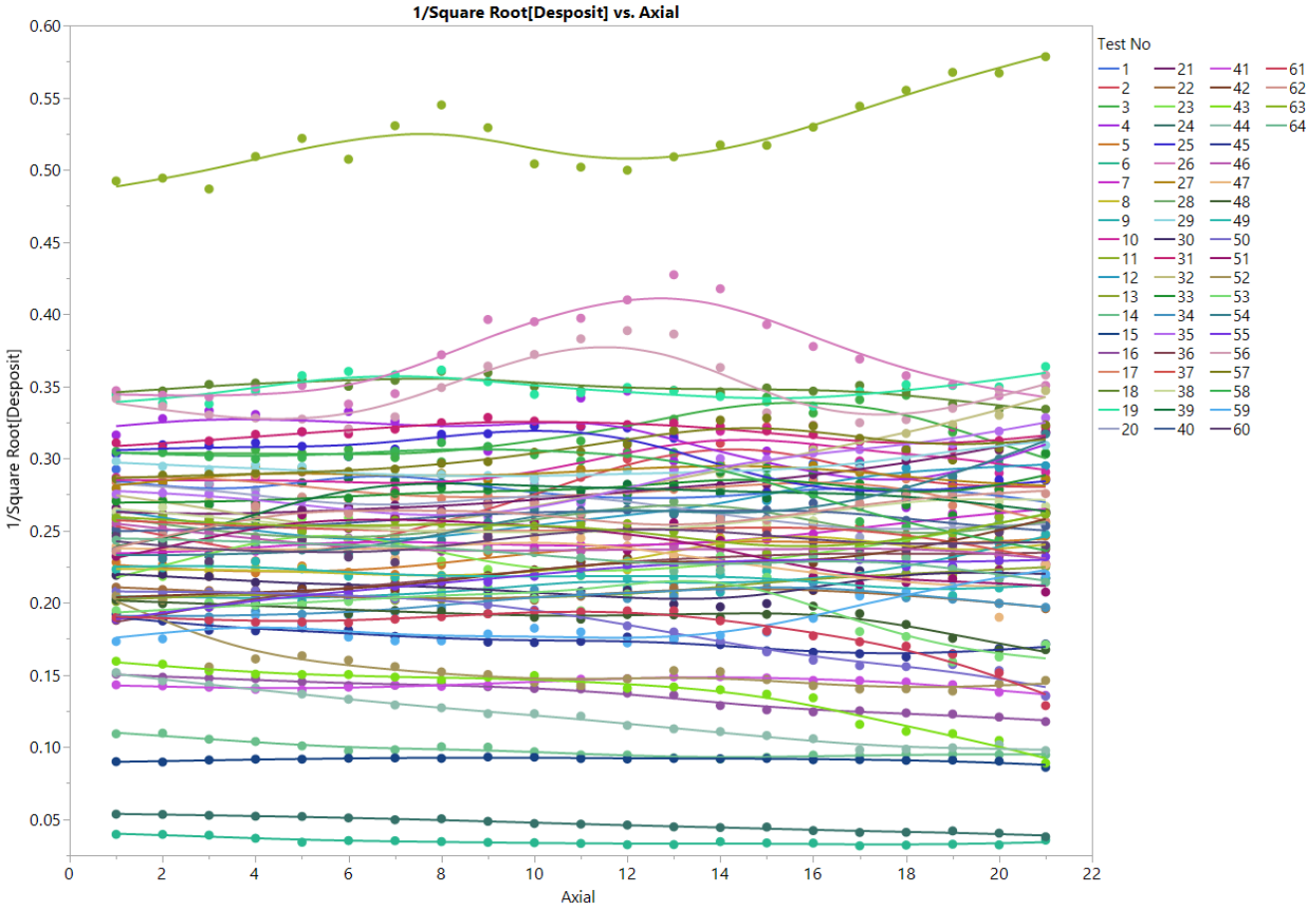
- The Box-Cox analysis curve suggests that an inverse square root (λ = -0.5) is the best transformation to use.



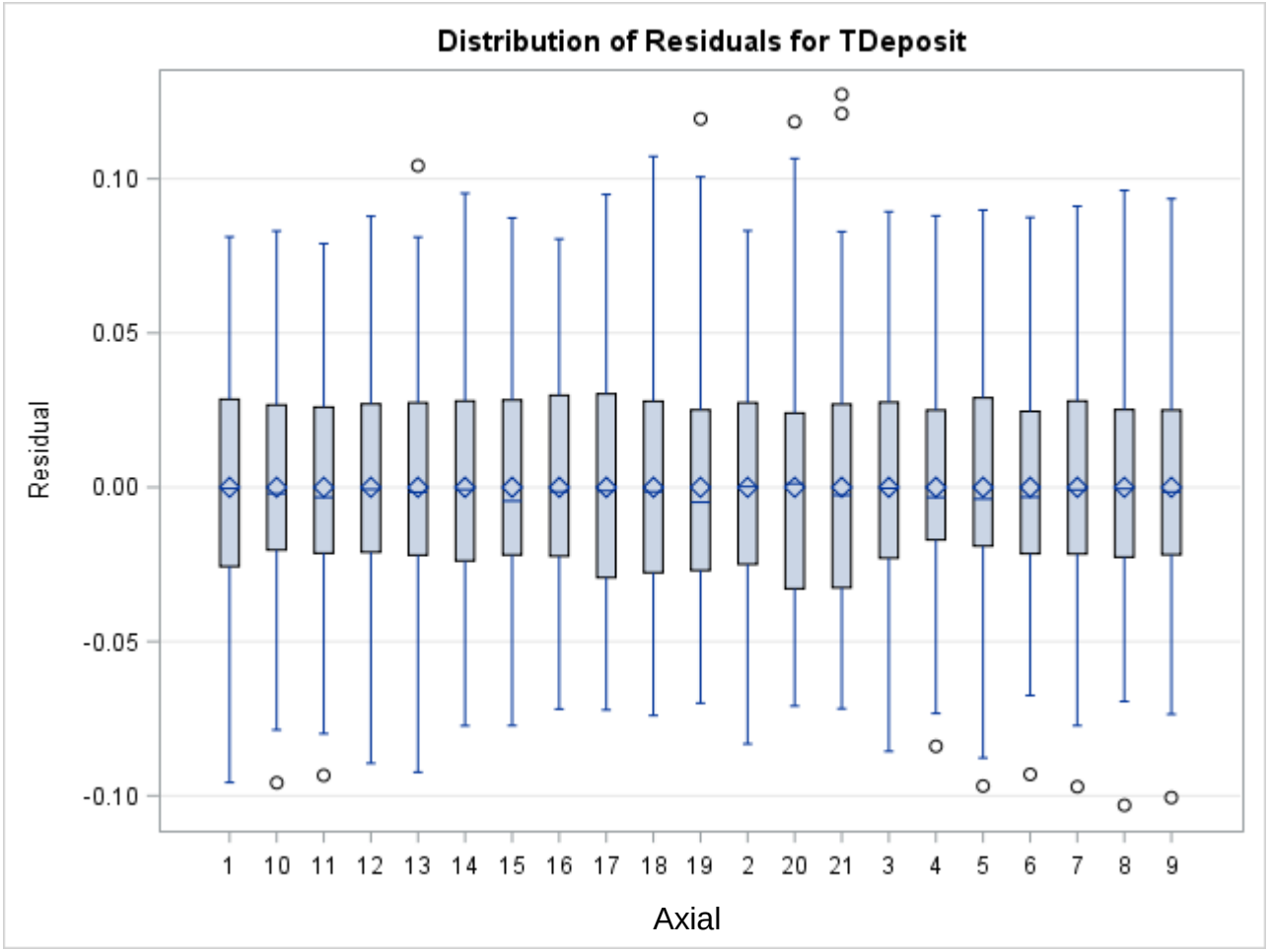
- Histogram of residuals from the inverse square root model suggests that the assumption of Normal distribution is achieved.



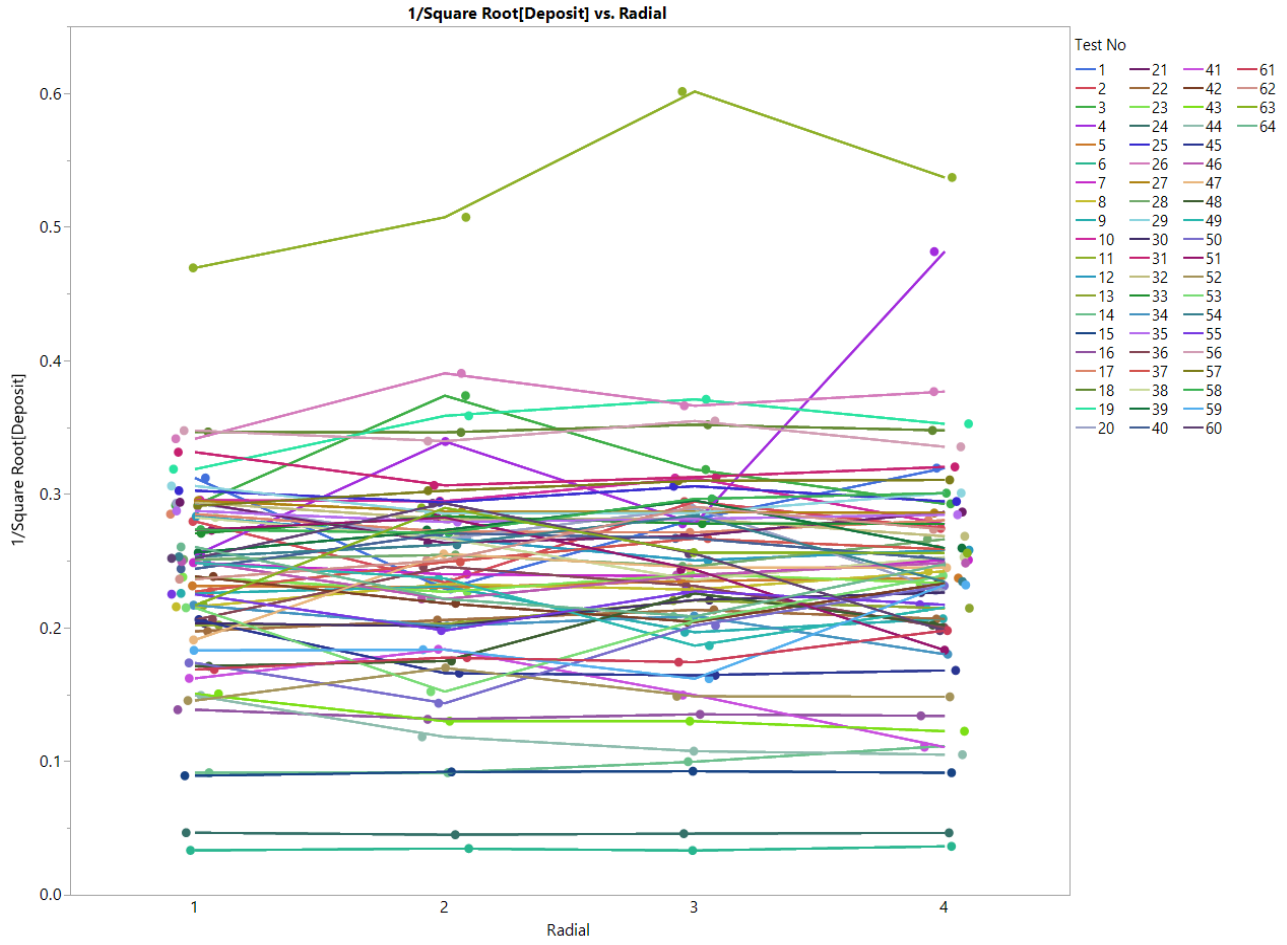
Deposit by Axial Location



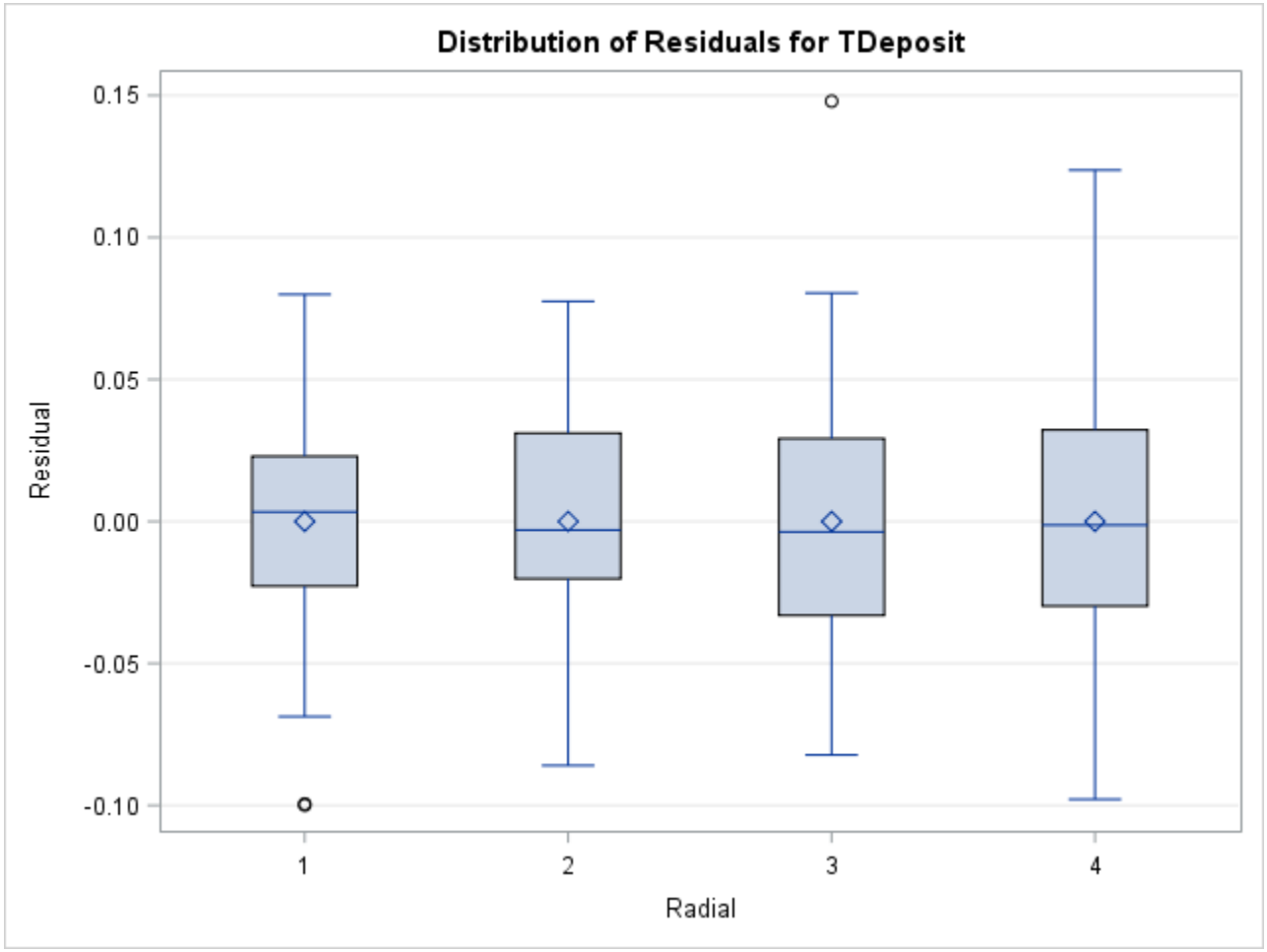
No significant Axial Location differences



Deposit by Radial Location



No significant Radial Location differences



ANOVA Results

- There is convergence of ANOVA results among deposit thickness responses so the results for Deposit (average of 84 measurements) is presented in detail in the following slides.

1/sqrt transformation	Deposit	R1	R2	R3	R4	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20	A21	SlopeT
Source	Prob > F	Prob > F	Prob > F	Prob > F	Prob > F	Prob > F	Prob > F	Prob > F	Prob > F	Prob > F	Prob > F	Prob > F	Prob > F	Prob > F	Prob > F	Prob > F	Prob > F	Prob > F	Prob > F	Prob > F	Prob > F	Prob > F	Prob > F	Prob > F	Prob > F	Prob > F	Prob > F
Biodiesel	0.91	0.71	0.96	0.97	0.90	0.92	0.98	0.95	0.98	0.90	0.91	0.90	0.89	0.91	0.99	1.00	0.87	0.66	0.70	0.75	0.73	0.70	0.70	0.70	0.64	0.54	0.16
Sodium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11
Glycerin	0.19	0.22	0.28	0.33	0.08	0.11	0.11	0.19	0.27	0.30	0.22	0.19	0.20	0.22	0.20	0.18	0.15	0.17	0.18	0.19	0.20	0.29	0.30	0.24	0.13	0.15	0.93
Corrosion Inibitor	0.83	0.83	0.94	0.63	0.89	0.91	0.98	1.00	0.92	0.82	0.85	0.78	0.84	0.94	0.94	0.93	0.89	0.78	0.83	0.87	0.70	0.68	0.67	0.60	0.63	0.81	0.43
Mono Acid Lubricity Additive	0.93	0.82	0.65	0.91	0.63	0.82	0.86	0.99	0.88	0.85	0.91	0.99	0.96	0.89	0.83	0.83	0.95	0.85	0.81	0.84	0.95	0.83	0.90	0.98	0.86	0.98	0.89
Detergent Additive	0.63	0.53	0.36	0.72	0.89	0.78	0.72	0.81	0.85	0.90	0.95	0.94	0.98	0.98	0.76	0.61	0.67	0.54	0.48	0.40	0.38	0.37	0.36	0.35	0.19	0.09	0.00
Cetane Number Improver	0.42	0.36	0.75	0.34	0.42	0.45	0.44	0.51	0.48	0.40	0.33	0.27	0.32	0.44	0.46	0.47	0.47	0.49	0.52	0.50	0.42	0.40	0.37	0.43	0.41	0.43	0.90
Conductivity Additive	0.13	0.09	0.20	0.16	0.23	0.19	0.20	0.23	0.25	0.22	0.23	0.21	0.21	0.17	0.15	0.20	0.16	0.10	0.09	0.10	0.08	0.07	0.08	0.09	0.09	0.11	0.10
Biodiesel*Sodium	0.83	0.28	0.68	0.98	0.94	0.82	0.86	0.72	0.82	0.91	0.86	0.77	0.76	0.72	0.76	0.66	0.61	0.55	0.68	0.81	0.93	0.90	0.86	0.99	0.95	0.90	0.71
Biodiesel*Glycerin	0.43	0.20	0.25	1.00	0.43	0.43	0.37	0.31	0.23	0.25	0.29	0.34	0.41	0.46	0.43	0.49	0.52	0.56	0.54	0.54	0.56	0.55	0.51	0.51	0.50	0.65	0.35
Biodiesel*Corrosion Inibitor	0.87	0.51	0.87	0.92	0.73	0.80	0.78	0.64	0.62	0.68	0.73	0.84	0.89	0.85	0.73	0.69	0.85	0.94	0.95	0.93	0.94	0.88	0.85	0.96	0.97	0.97	0.28
Biodiesel*Mono Acid Lubricity Additive	0.76	0.68	0.44	0.52	0.75	0.88	0.88	0.72	0.60	0.62	0.62	0.64	0.73	0.82	0.80	0.87	0.94	0.97	0.81	0.78	0.76	0.71	0.78	0.81	0.82	0.82	0.87
Biodiesel*Detergent Additive	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12
Biodiesel*Cetane Number Improver	0.16	0.35	0.09	0.13	0.29	0.38	0.34	0.26	0.14	0.10	0.13	0.15	0.12	0.12	0.14	0.18	0.17	0.10	0.10	0.17	0.24	0.18	0.17	0.18	0.22	0.16	0.57
Biodiesel*Conductivity Additive	0.05	0.13	0.02	0.20	0.02	0.04	0.03	0.06	0.07	0.06	0.05	0.09	0.11	0.09	0.08	0.06	0.06	0.08	0.09	0.10	0.08	0.05	0.05	0.05	0.06	0.06	0.83
Sodium*Glycerin	0.08	0.15	0.08	0.07	0.05	0.14	0.13	0.09	0.12	0.17	0.14	0.12	0.12	0.12	0.09	0.05	0.05	0.06	0.05	0.06	0.11	0.09	0.07	0.05	0.04	0.05	0.16
Sodium*Corrosion Inibitor	0.24	0.19	0.18	0.37	0.53	0.24	0.22	0.26	0.26	0.29	0.32	0.27	0.29	0.31	0.37	0.36	0.38	0.26	0.22	0.25	0.30	0.22	0.16	0.24	0.16	0.14	0.47
Sodium*Mono Acid Lubricity Additive	0.05	0.15	0.05	0.10	0.02	0.16	0.14	0.11	0.12	0.14	0.08	0.07	0.08	0.07	0.06	0.04	0.04	0.05	0.03	0.02	0.03	0.04	0.05	0.05	0.04	0.03	0.07
Sodium*Detergent Additive	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.19
Sodium*Cetane Number Improver	0.43	0.20	0.26	0.65	0.59	0.29	0.30	0.30	0.27	0.26	0.23	0.26	0.30	0.35	0.31	0.32	0.30	0.30	0.35	0.47	0.64	0.91	0.97	0.93	0.91	0.96	0.02
Sodium*Conductivity Additive	0.43	0.31	0.54	0.54	0.84	0.56	0.54	0.44	0.51	0.58	0.77	0.69	0.54	0.49	0.55	0.46	0.47	0.46	0.51	0.52	0.39	0.25	0.25	0.31	0.25	0.21	0.16
Glycerin*Corrosion Inibitor	0.69	0.52	0.93	0.69	0.82	0.73	0.75	0.78	0.82	0.73	0.80	0.91	0.88	0.79	0.77	0.79	0.88	0.75	0.66	0.66	0.64	0.59	0.52	0.52	0.52	0.47	0.33
Glycerin*Mono Acid Lubricity Additive	0.19	0.15	0.22	0.21	0.19	0.25	0.24	0.28	0.27	0.26	0.19	0.16	0.18	0.18	0.17	0.12	0.12	0.11	0.13	0.15	0.21	0.27	0.26	0.18	0.21	0.21	0.64
Glycerin*Detergent Additive	0.84	0.41	0.81	0.73	0.73	0.78	0.92	0.98	0.89	0.93	1.00	1.00	0.91	0.85	0.84	0.88	0.77	0.73	0.69	0.67	0.71	0.83	0.94	0.91	0.81	0.72	0.53
Glycerin*Cetane Number Improver	0.12	0.08	0.26	0.08	0.21	0.08	0.07	0.08	0.08	0.09	0.06	0.06	0.09	0.15	0.14	0.15	0.22	0.19	0.20	0.16	0.15	0.16	0.16	0.12	0.14	0.24	0.42
Glycerin*Conductivity Additive	0.07	0.16	0.08	0.05	0.15	0.06	0.05	0.08	0.04	0.02	0.02	0.02	0.03	0.05	0.06	0.06	0.09	0.09	0.13	0.20	0.16	0.16	0.15	0.14	0.14	0.16	0.15
Corrosion Inibitor*Mono Acid Lubricity Additive	0.51	0.74	0.52	0.54	0.53	0.93	0.85	0.85	0.71	0.79	0.77	0.85	0.87	0.83	0.72	0.61	0.51	0.51	0.37	0.27	0.22	0.20	0.22	0.24	0.23	0.29	0.01
Corrosion Inibitor*Detergent Additive	0.75	0.77	0.44	0.71	0.61	0.85	0.86	0.84	0.87	0.81	0.73	0.76	0.86	0.93	0.96	0.96	0.94	0.85	0.68	0.57	0.58	0.53	0.46	0.47	0.71	0.74	0.33
Corrosion Inibitor*Cetane Number Improver	0.41	0.43	0.22	0.42	0.52	0.60	0.62	0.58	0.53	0.46	0.37	0.40	0.50	0.49	0.47	0.43	0.44	0.54	0.59	0.51	0.38	0.33	0.28	0.25	0.23	0.30	0.24
Corrosion Inibitor*Conductivity Additive	0.11	0.11	0.21	0.13	0.05	0.20	0.16	0.12	0.13	0.14	0.11	0.13	0.17	0.19	0.16	0.11	0.14	0.16	0.15	0.10	0.07	0.09	0.09	0.06	0.04	0.05	0.16
Mono Acid Lubricity Additive*Detergent Additive	0.43	0.84	0.07	0.48	0.62	0.58	0.53	0.60	0.41	0.40	0.48	0.51	0.41	0.40	0.38	0.35	0.48	0.51	0.44	0.38	0.40	0.41	0.45	0.53	0.41	0.28	0.56
Mono Acid Lubricity Additive*Cetane Number Improver	0.10	0.03	0.06	0.14	0.49	0.09	0.08	0.14	0.13	0.13	0.10	0.12	0.18	0.25	0.26	0.24	0.32	0.25	0.18	0.12	0.09	0.07	0.04	0.03	0.03	0.05	0.17
Mono Acid Lubricity Additive*Conductivity Additive	0.07	0.07	0.17	0.10	0.04	0.07	0.05	0.03	0.05	0.07	0.05	0.07	0.11	0.12	0.10	0.10	0.07	0.09	0.06	0.05	0.07	0.10	0.10	0.12	0.09	0.08	0.85
Detergent Additive*Cetane Number Improver	0.77	0.90	0.62	0.53	0.87	0.72	0.73	0.84	0.58	0.51	0.71	0.76	0.69	0.69	0.79	0.86	0.99	0.85	0.81	0.94	0.97	0.70	0.63	0.78	0.74	0.93	0.70
Detergent Additive*Conductivity Additive	0.41	0.29	0.16	0.32	0.85	0.38	0.36	0.41	0.40	0.52	0.61	0.57	0.54	0.48	0.48	0.39	0.38	0.29	0.29	0.30	0.34	0.38	0.44	0.44	0.41	0.33	0.60
Cetane Number Improver*Conductivity Additive	0.72	0.57	0.88	0.86	0.46	0.66	0.64	0.74	0.75	0.71	0.68	0.66	0.75	0.94	0.99	0.95	0.92	0.85	0.84	0.76	0.66	0.67	0.69	0.69	0.49	0.45	0.65

1/sqrt(Deposit) ANOVA

Summary of Fit

RSquare	0.772485
RSquare Adj	0.469132
Root Mean Square Error	0.05673
Mean of Response	0.238183
Observations (or Sum Wgts)	64

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	36	0.29503343	0.008195	2.5465
Error	27	0.08689421	0.003218	Prob > F
C. Total	63	0.38192764		0.0069*

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Biodiesel	1	1	0.00004403	0.0137	0.9077
Sodium	1	1	0.09079904	28.2133	<.0001*
Glycerin	1	1	0.00581604	1.8072	0.1900
Corrosion Inibitor	1	1	0.00015942	0.0495	0.8255
Mono Acid Lubricity Additive	1	1	0.00002739	0.0085	0.9272
Detergent Additive	1	1	0.00075574	0.2348	0.6319
Cetane Number Improver	1	1	0.00216136	0.6716	0.4197
Conductivity Additive	1	1	0.00800700	2.4880	0.1264
Biodiesel*Sodium	1	1	0.00015484	0.0481	0.8280
Biodiesel*Glycerin	1	1	0.00203290	0.6317	0.4337
Biodiesel*Corrosion Inibitor	1	1	0.00009186	0.0285	0.8671

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Biodiesel*Mono Acid Lubricity Additive	1	1	0.00031815	0.0989	0.7556
Biodiesel*Detergent Additive	1	1	0.03582981	11.1331	0.0025*
Biodiesel*Cetane Number Improver	1	1	0.00679794	2.1123	0.1576
Biodiesel*Conductivity Additive	1	1	0.01300661	4.0414	0.0545
Sodium*Glycerin	1	1	0.01072300	3.3319	0.0790
Sodium*Corrosion Inibitor	1	1	0.00473697	1.4719	0.2356
Sodium*Mono Acid Lubricity Additive	1	1	0.01318476	4.0968	0.0530
Sodium*Detergent Additive	1	1	0.03055602	9.4944	0.0047*
Sodium*Cetane Number Improver	1	1	0.00205073	0.6372	0.4317
Sodium*Conductivity Additive	1	1	0.00210925	0.6554	0.4253
Glycerin*Corrosion Inibitor	1	1	0.00053856	0.1673	0.6857
Glycerin*Mono Acid Lubricity Additive	1	1	0.00589092	1.8304	0.1873
Glycerin*Detergent Additive	1	1	0.00013314	0.0414	0.8403
Glycerin*Cetane Number Improver	1	1	0.00847800	2.6343	0.1162
Glycerin*Conductivity Additive	1	1	0.01149384	3.5714	0.0696
Corrosion Inibitor*Mono Acid Lubricity Additive	1	1	0.00144530	0.4491	0.5085
Corrosion Inibitor*Detergent Additive	1	1	0.00033868	0.1052	0.7481
Corrosion Inibitor*Cetane Number Improver	1	1	0.00228323	0.7095	0.4070
Corrosion Inibitor*Conductivity Additive	1	1	0.00902543	2.8044	0.1056
Mono Acid Lubricity Additive*Detergent Additive	1	1	0.00202680	0.6298	0.4344
Mono Acid Lubricity Additive*Cetane Number Improver	1	1	0.00931451	2.8942	0.1004
Mono Acid Lubricity Additive*Conductivity Additive	1	1	0.01176895	3.6569	0.0665
Detergent Additive*Cetane Number Improver	1	1	0.00027133	0.0843	0.7738
Detergent Additive*Conductivity Additive	1	1	0.00223084	0.6932	0.4124
Cetane Number Improver*Conductivity Additive	1	1	0.00043105	0.1339	0.7172

1/sqrt(Deposit) ANOVA Results

- Significant effects (p-value≤0.05)
  - Sodium
  - Biodiesel*Detergent Additive
  - Sodium*Detergent Additive

- Marginal effects (0.05<p-value≤0.10)
  - Biodiesel*Conductivity Additive
  - Sodium*Glycerin
  - Sodium*Mono Acid Lubricity Additive
  - Glycerin*Conductivity Additive
  - Mono Acid Lubricity Additive*Conductivity Additive

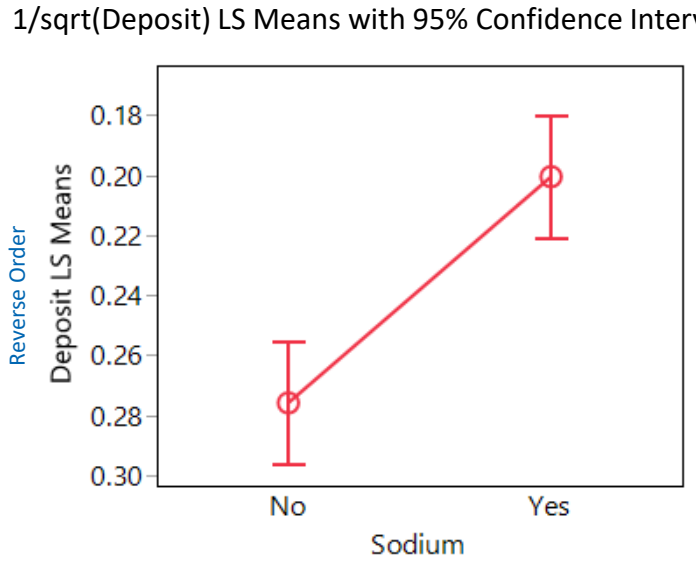
- Not statistically significant effects (p-value>0.10)
  - Corrosion Inhibitor
  - Cetane Number Improver

*Note: **p-value** is the probability of getting something more extreme than your result, when there is no effect in the population*

- Not statistically significant effects (p-value>0.10)
  - Biodiesel*Sodium
  - Biodiesel*Glycerin
  - Biodiesel*Corrosion Inhibitor
  - Biodiesel*Mono Acid Lubricity Additive
  - Biodiesel*Cetane Number Improver
  - Sodium*Corrosion Inhibitor
  - Sodium*Cetane Number Improver
  - Sodium*Conductivity Additive
  - Glycerin*Corrosion Inhibitor
  - Glycerin*Mono Acid Lubricity Additive
  - Glycerin*Detergent Additive
  - Glycerin*Cetane Number Improver
  - Corrosion Inhibitor*Mono Acid Lubricity Additive
  - Corrosion Inhibitor*Detergent Additive
  - Corrosion Inhibitor*Cetane Number Improver
  - Corrosion Inhibitor*Conductivity Additive
  - Mono Acid Lubricity Additive*Detergent Additive
  - Mono Acid Lubricity Additive*Cetane Number Improver
  - Detergent Additive*Cetane Number Improver
  - Detergent Additive*Conductivity Additive
  - Cetane Number Improver*Conductivity Additive

Sodium Effect on 1/sqrt(Deposit)

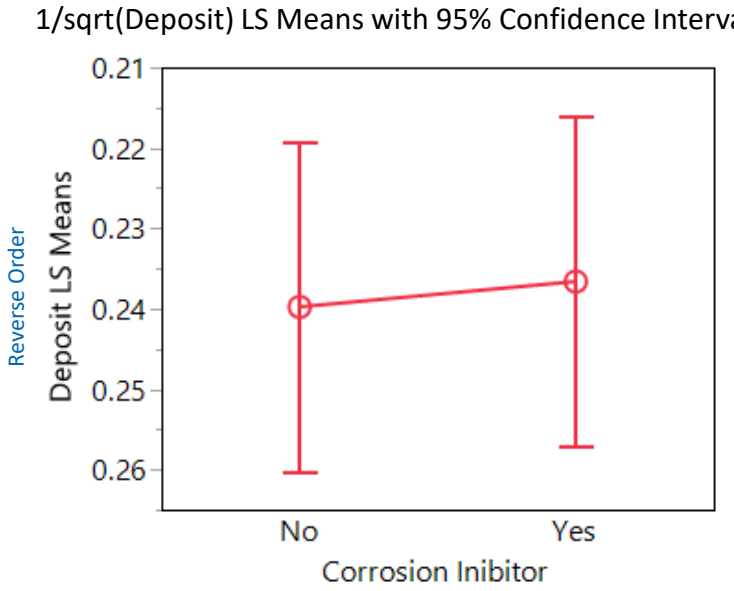
- Sodium effect on deposit thickness is statistically significant
  - Sodium significantly increases deposit thickness



Sodium	1/sqrt(Deposit) LSMean	Deposit LSMean
No	0.2758	13.14
Yes	0.2005	24.87

Corrosion Inhibitor Effect on 1/sqrt(Deposit)

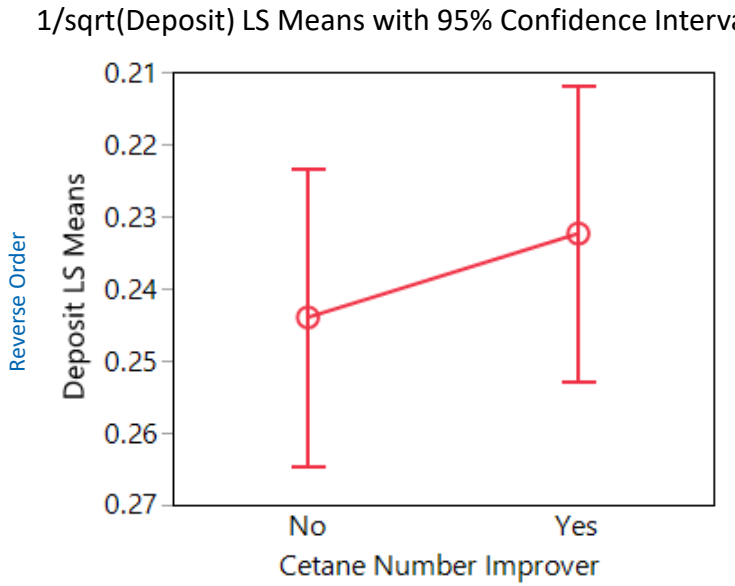
- Corrosion Inhibitor effect on deposit thickness is not statistically significant
  - Presence or absence of corrosion inhibitor is not statistically different



Corrosion Inhibitor	1/sqrt(Deposit) LSMean	Deposit LSMean
No	0.2398	17.39
Yes	0.2366	17.86

Cetane Number Improver Effect on 1/sqrt(Deposit)

- Cetane Number Improver effect on deposit thickness is not statistically significant
  - Presence or absence of cetane number improver is not statistically different

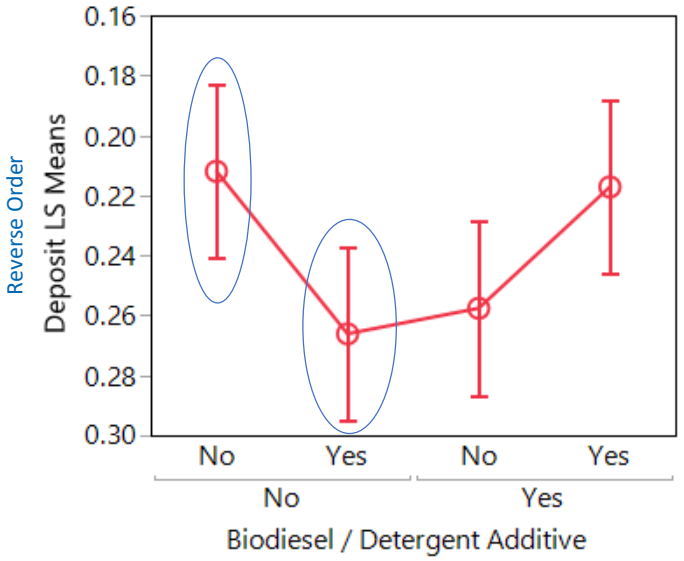


Cetane Number Improver	1/sqrt(Deposit) LSMean	Deposit LSMean
No	0.2440	16.80
Yes	0.2324	18.52

Biodiesel-Detergent Additive Effect on 1/sqrt(Deposit)

- Biodiesel-Detergent Additive interaction effect is statistically significant
  - Without biodiesel, presence of detergent additive has significantly lower deposit thickness than absence of detergent additive
  - With biodiesel, presence or absence of detergent additive is not statistically different

1/sqrt(Deposit) LS Means with 95% Confidence Intervals



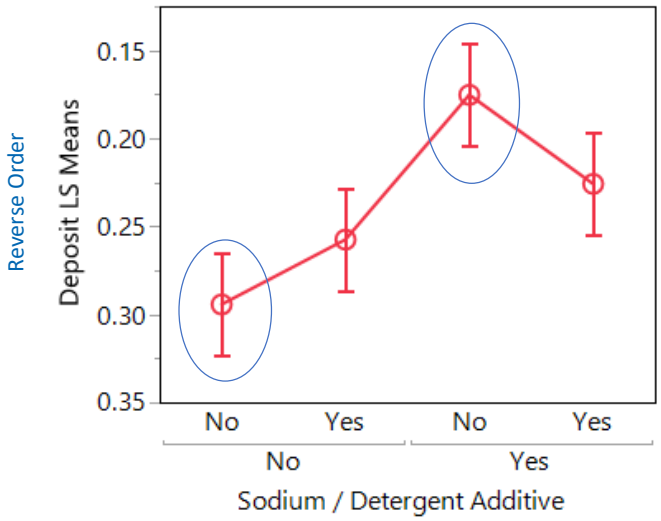
Biodiesel, Detergent Additive	1/sqrt(Deposit) LSMean	Deposit LSMean
No,No	0.2119	22.27
No,Yes	0.2661	14.12
Yes,No	0.2576	15.07
Yes,Yes	0.2171	21.21

Level	- Level	Difference	p-Value
No,Yes	No,No	0.0542	0.0539
No,Yes	Yes,Yes	0.0490	0.0930
Yes,No	No,No	0.0457	0.1288
Yes,No	Yes,Yes	0.0404	0.2069
No,Yes	Yes,No	0.0085	0.9736
Yes,Yes	No,No	0.0052	0.9937

Sodium-Detergent Additive Effect on 1/sqrt(Deposit)

- Sodium-Detergent Additive interaction effect is statistically significant
  - Without detergent additive, presence of sodium has significantly higher deposit thickness than absence of sodium
  - With detergent additive, presence or absence of sodium is not statistically different

1/sqrt(Deposit) LS Means with 95% Confidence Intervals

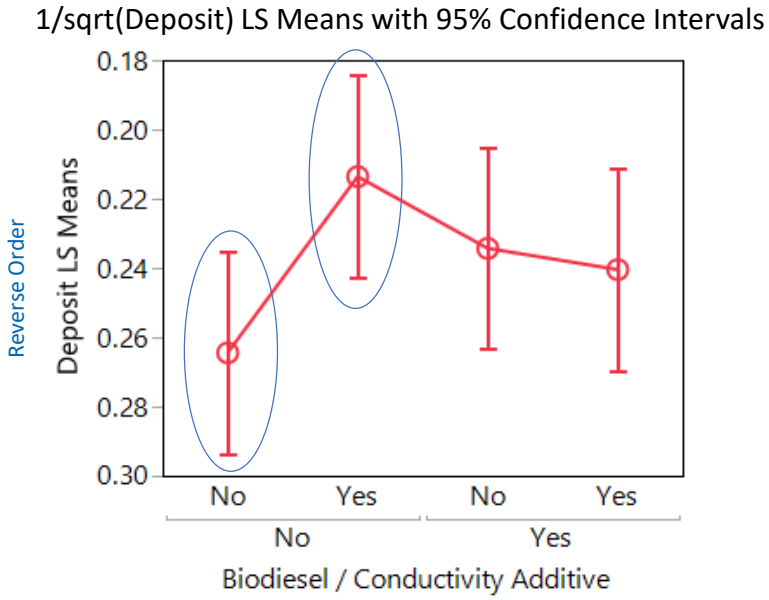


Sodium, Detergent Additive	1/sqrt(Deposit) LSMean	Deposit LSMean
No,No	0.2943	11.55
Yes,No	0.1752	32.57
No,Yes	0.2574	15.09
Yes,Yes	0.2258	19.61

Level	- Level	Difference	p-Value
No,No	Yes,No	0.1190	<.0001*
No,Yes	Yes,No	0.0822	0.0018*
No,No	Yes,Yes	0.0685	0.0103*
Yes,Yes	Yes,No	0.0506	0.0790
No,No	No,Yes	0.0368	0.2790
No,Yes	Yes,Yes	0.0316	0.4080

Biodiesel-Conductivity Additive Effect on 1/sqrt(Deposit)

- Biodiesel-Conductivity Additive interaction effect is marginally significant
  - Without biodiesel, presence of conductivity additive has marginally higher deposit thickness than absence of conductivity additive
  - With biodiesel, presence or absence of conductivity additive is not statistically different

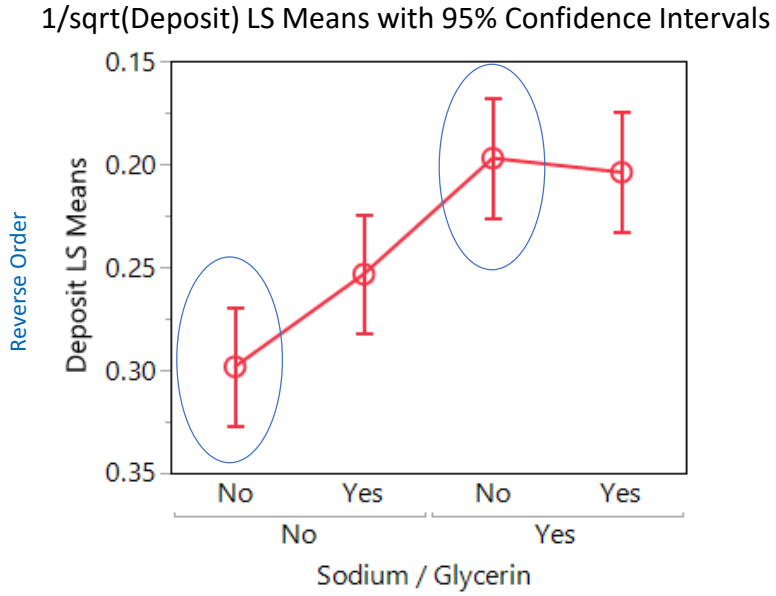


Biodiesel, Conductivity Additive	1/sqrt(Deposit) LSMean	Deposit LSMean
No,No	0.2645	14.30
No,Yes	0.2136	21.92
Yes,No	0.2343	18.22
Yes,Yes	0.2404	17.30

Level	- Level	Difference	p-Value
No,No	No,Yes	0.0509	0.0765
No,No	Yes,No	0.0302	0.4490
Yes,Yes	No,Yes	0.0269	0.5472
No,No	Yes,Yes	0.0240	0.6333
Yes,No	No,Yes	0.0207	0.7321
Yes,Yes	Yes,No	0.0061	0.9898

Sodium-Glycerin Effect on 1/sqrt(Deposit)

- Sodium-Glycerin interaction effect is marginally significant
  - Without glycerin, presence of sodium has significantly higher deposit thickness than absence of sodium
  - With glycerin, presence of sodium has marginally higher deposit thickness than absence of sodium



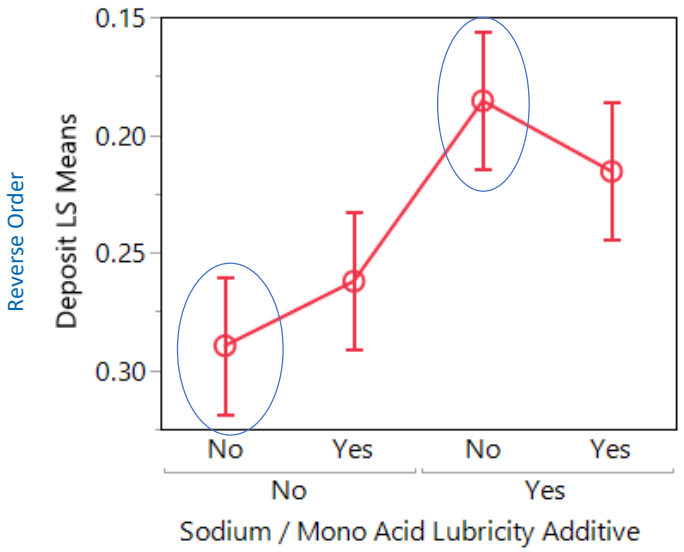
Sodium, Glycerin	1/sqrt(Deposit) LSMean	Deposit LSMean
No,No	0.2983	11.24
Yes,No	0.1971	25.74
No,Yes	0.2534	15.58
Yes,Yes	0.2039	24.05

Level	- Level	Difference	p-Value
No,No	Yes,No	0.1012	0.0002*
No,No	Yes,Yes	0.0944	0.0004*
No,Yes	Yes,No	0.0563	0.0430*
No,Yes	Yes,Yes	0.0494	0.0887
No,No	No,Yes	0.0450	0.1377
Yes,Yes	Yes,No	0.0068	0.9862

Sodium-Mono Acid Lubricity Additive Effect on 1/sqrt(Deposit)

- Sodium-Mono Acid Lubricity Additive interaction effect is marginally significant
  - Without mono acid lubricity additive, presence of sodium has significantly higher deposit thickness than absence of sodium
  - With mono acid lubricity additive, presence or absence of sodium is not statistically different

1/sqrt(Deposit) LS Means with 95% Confidence Intervals



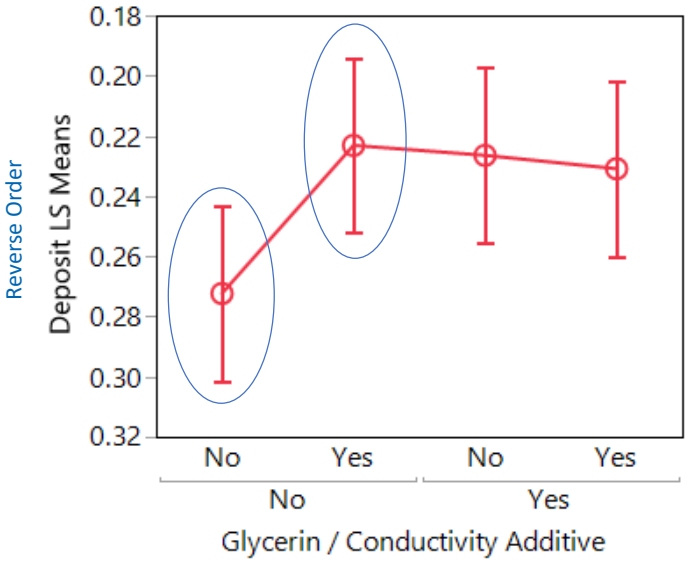
Sodium, Mono Acid Lubricity Additive	1/sqrt(Deposit) LSMean	Deposit LSMean
No,No	0.2895	11.93
Yes,No	0.1855	29.06
No,Yes	0.2622	14.55
Yes,Yes	0.2155	21.53

Level	- Level	Difference	p-Value
No,No	Yes,No	0.1040	0.0001*
No,Yes	Yes,No	0.0766	0.0037*
No,No	Yes,Yes	0.0740	0.0052*
No,Yes	Yes,Yes	0.0466	0.1174
Yes,Yes	Yes,No	0.0300	0.4534
No,No	No,Yes	0.0274	0.5307

Glycerin-Conductivity Additive Effect on 1/sqrt(Deposit)

- Glycerin-Conductivity Additive interaction effect is marginally significant
  - Without glycerin, presence of conductivity additive has marginally higher deposit thickness than absence of conductivity additive
  - With glycerin, presence or absence of conductivity additive is not statistically different

1/sqrt(Deposit) LS Means with 95% Confidence Intervals



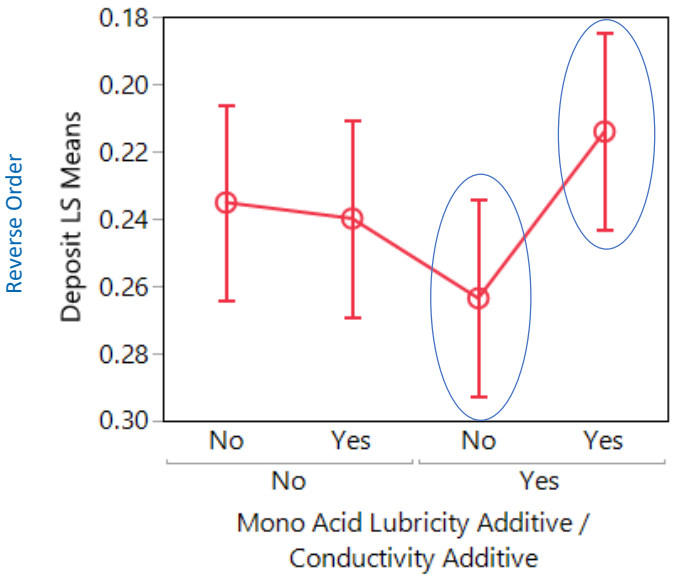
Glycerin, Conductivity Additive	1/sqrt(Deposit) LSMean	Deposit LSMean
No,No	0.2723	13.49
No,Yes	0.2231	20.09
Yes,No	0.2264	19.50
Yes,Yes	0.2309	18.76

Level	- Level	Difference	p-Value
No,No	No,Yes	0.0492	0.0912
No,No	Yes,No	0.0459	0.1263
No,No	Yes,Yes	0.0414	0.1899
Yes,Yes	No,Yes	0.0077	0.9801
Yes,Yes	Yes,No	0.0044	0.9961
Yes,No	No,Yes	0.0033	0.9984

Mono Acid Lubricity Additive-Conductivity Additive Effect on 1/sqrt(Deposit)

- Mono Acid Lubricity Additive-Conductivity Additive interaction effect is marginally significant
  - Without mono acid lubricity additive, presence or absence of conductivity additive is not statistically different
  - With mono acid lubricity additive, presence of conductivity additive has marginally higher deposit thickness than absence of conductivity additive

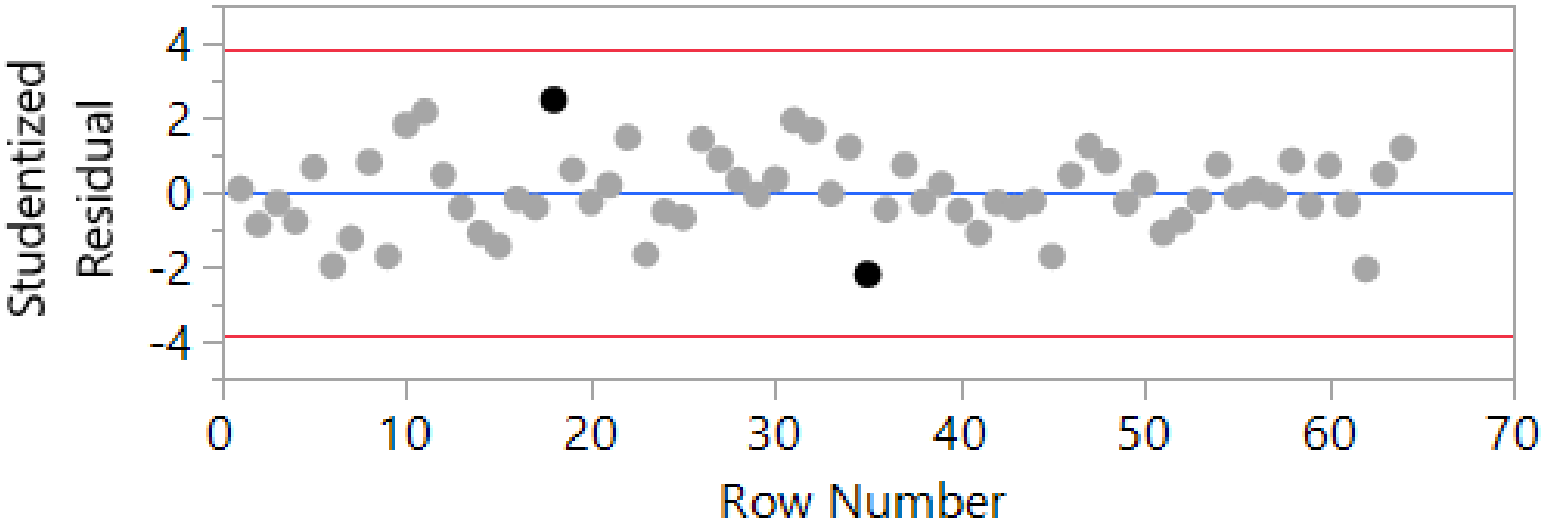
1/sqrt(Deposit) LS Means with 95% Confidence Intervals



Mono Acid Lubricity Additive, Conductivity Additive	1/sqrt(Deposit) LSMean	Deposit LSMean
No,No	0.2352	18.08
No,Yes	0.2399	17.37
Yes,No	0.2636	14.39
Yes,Yes	0.2141	21.82

Level	- Level	Difference	p-Value
Yes,No	Yes,Yes	0.0495	0.0883
Yes,No	No,No	0.0284	0.4998
No,Yes	Yes,Yes	0.0258	0.5788
Yes,No	No,Yes	0.0237	0.6440
No,No	Yes,Yes	0.0211	0.7219
No,Yes	No,No	0.0048	0.9952

No Statistical Outliers

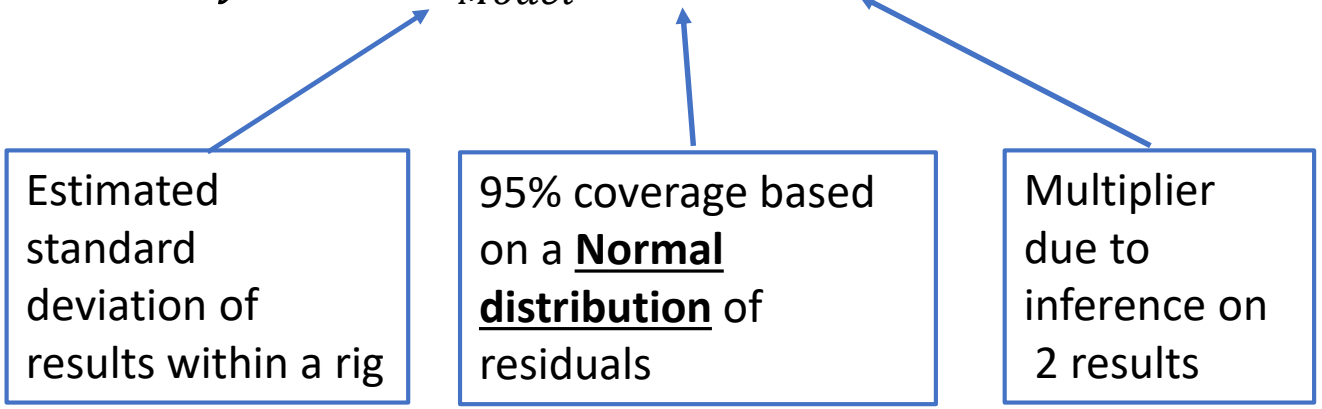


- All residuals fall within the 95% Confidence Limits so no statistical outliers
- Test number 18 has the highest residual followed by test number 35

Estimate of Repeatability

- Root Mean Square Error (RMSE) - estimate of standard deviation

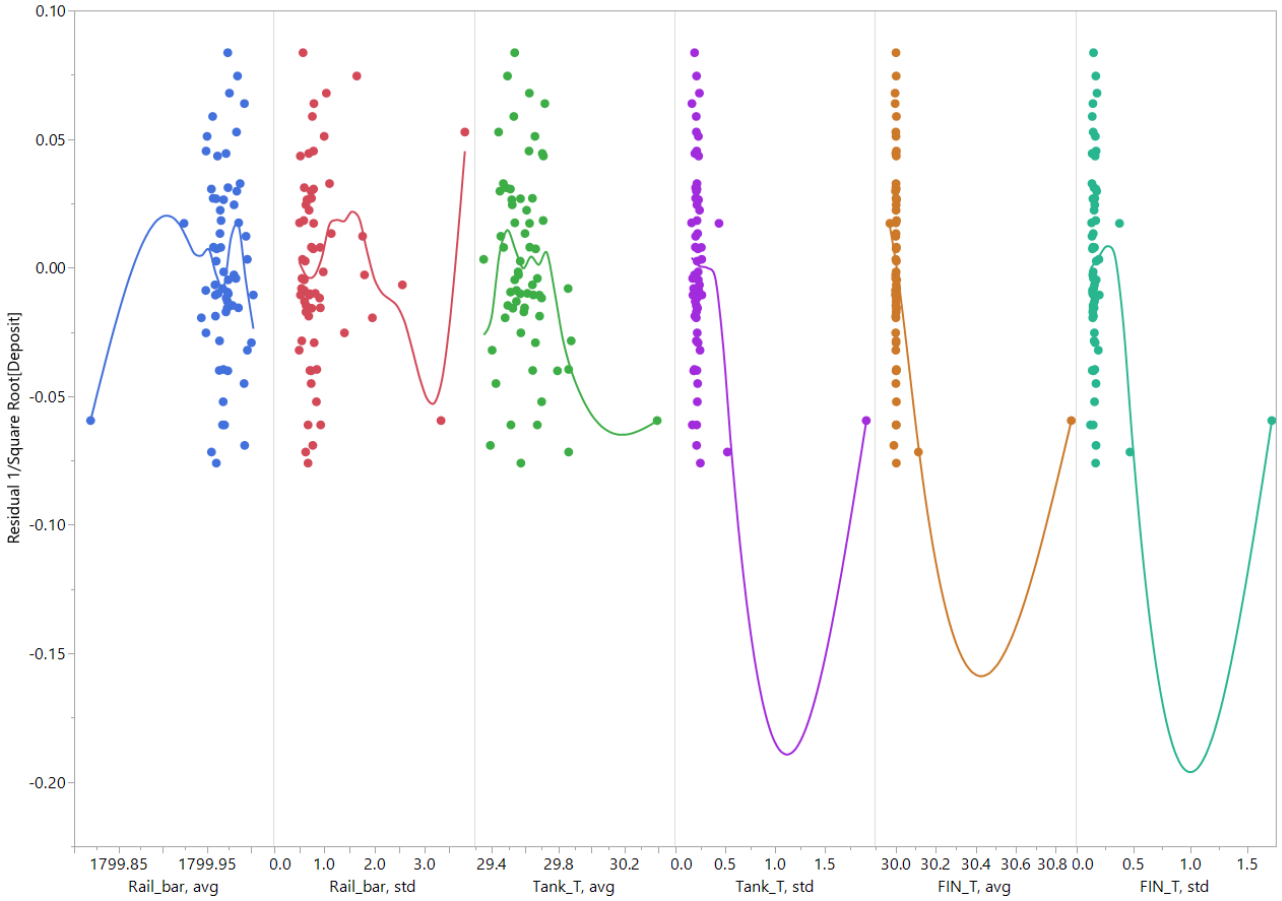
$$Test_Repeatability = RMSE_{Model} * 1.96 * \sqrt{2}$$



- 1/sqrt(Deposit) Model RMSE = 0.0567
- Repeatability, r = 0.1572
- Based upon the estimated standard deviation (RMSE) and repeatability (r), there is no significant difference between deposit thickness results of 10nm and 40nm. (A result of 10nm was arbitrarily chosen)

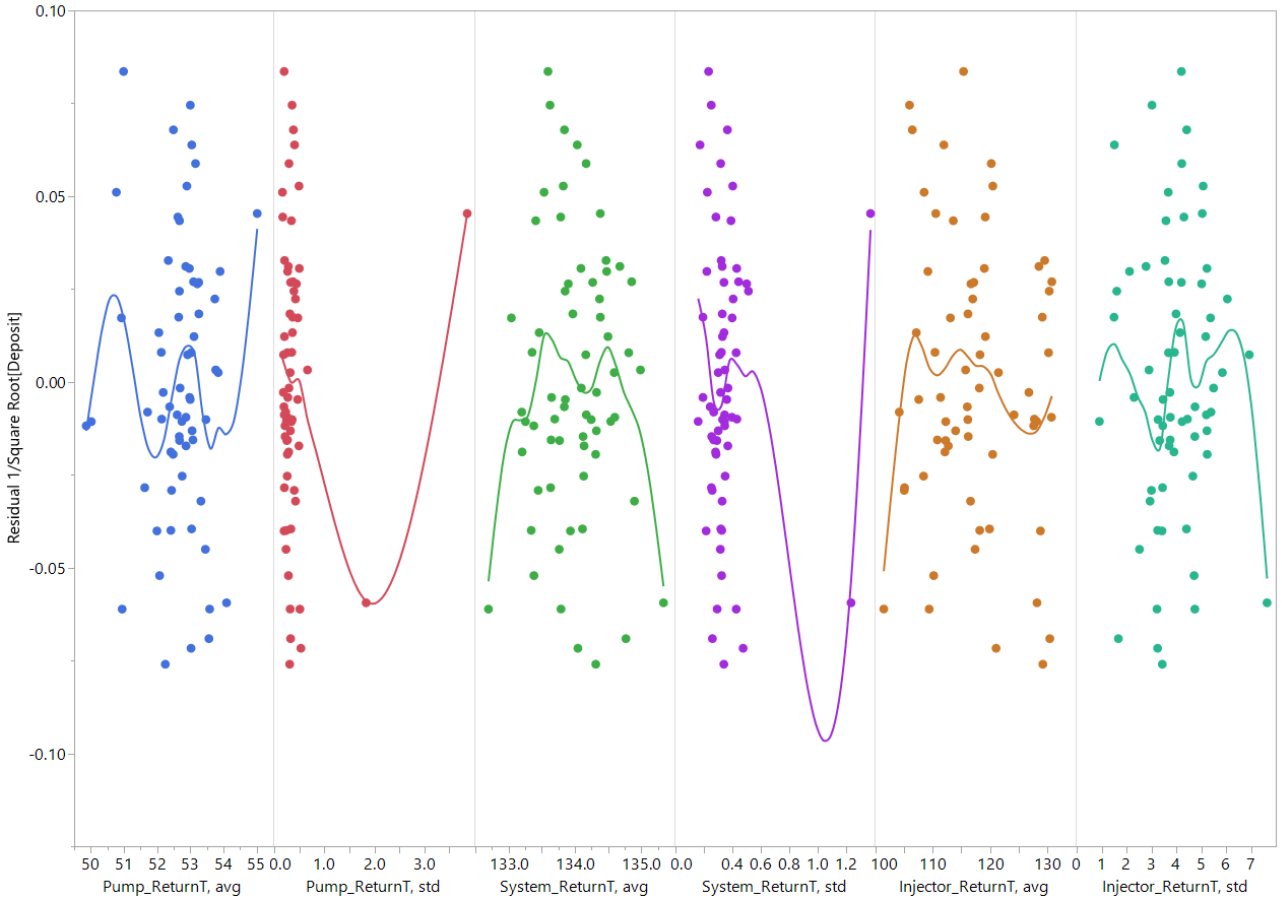
Appendix A
Residual Plots by Operational Parameters

Operational Parameters
Rail bar, Tank_T, FIN_T



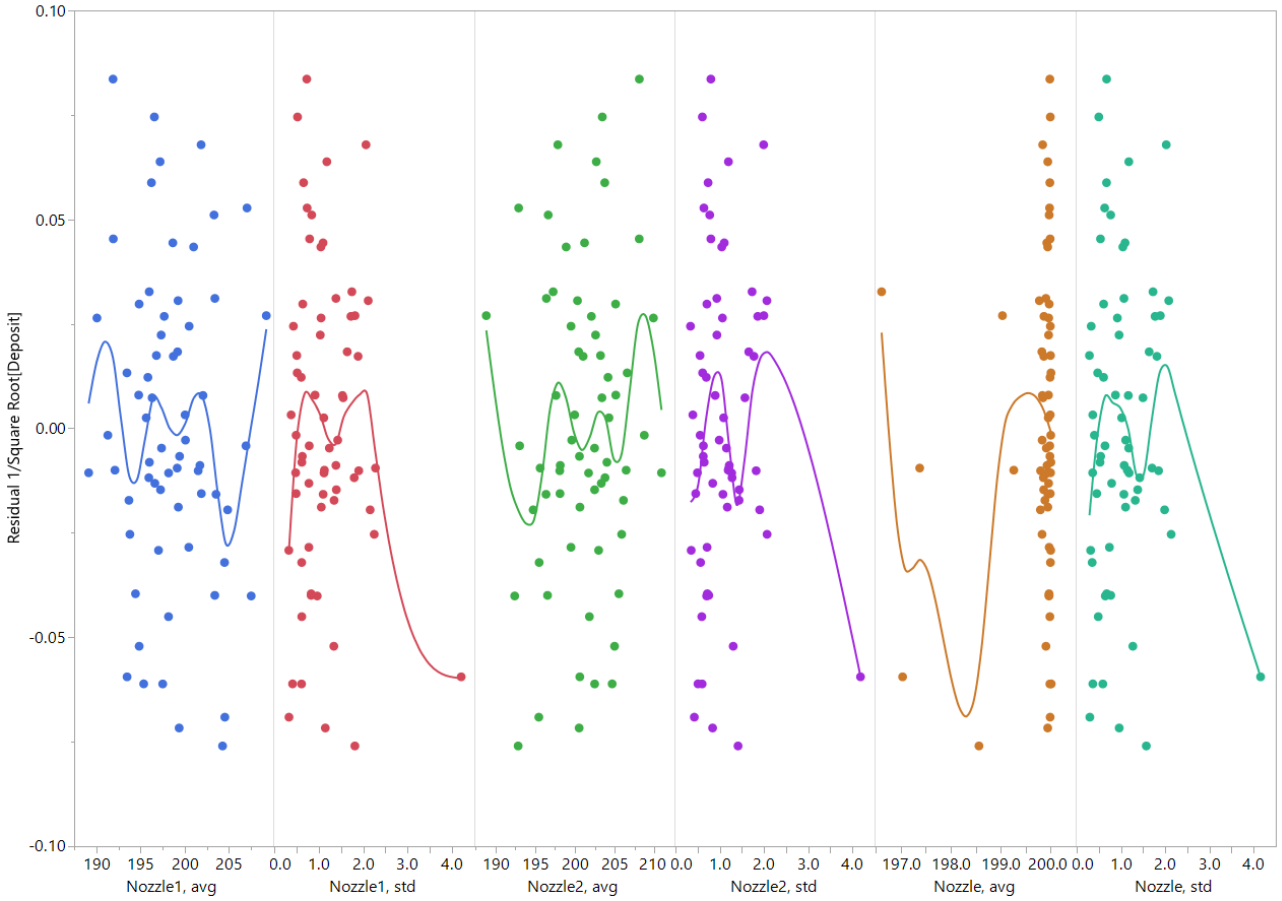
Test 23 seems to be different in terms of Rail bar, Tank_T and FIN_T

Operational Parameters Pump, System, Injector



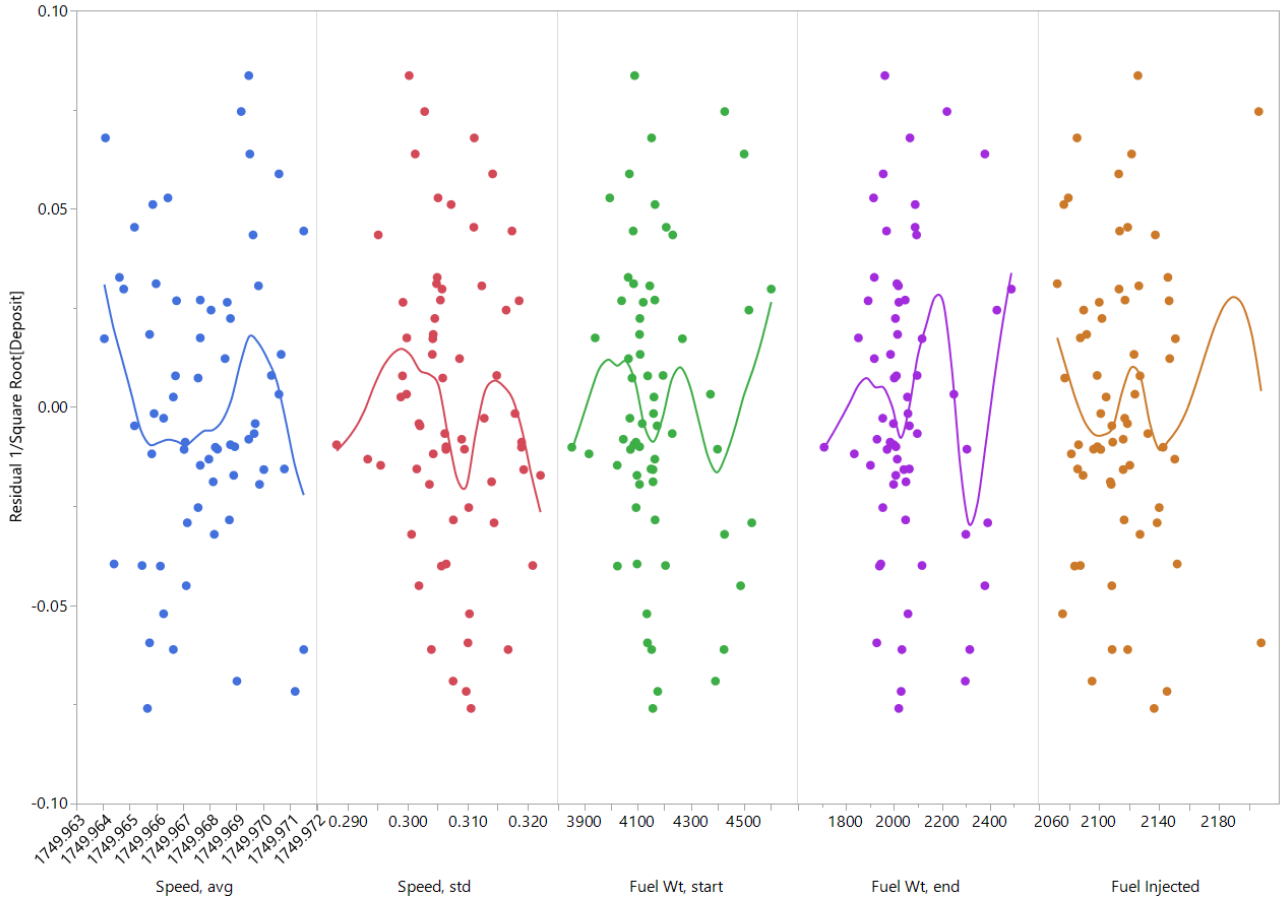
Tests 47 and 23 have higher Pump and System return std

Operational Parameters
Nozzle



Test 23 seems to be different in terms of Nozzle parameters

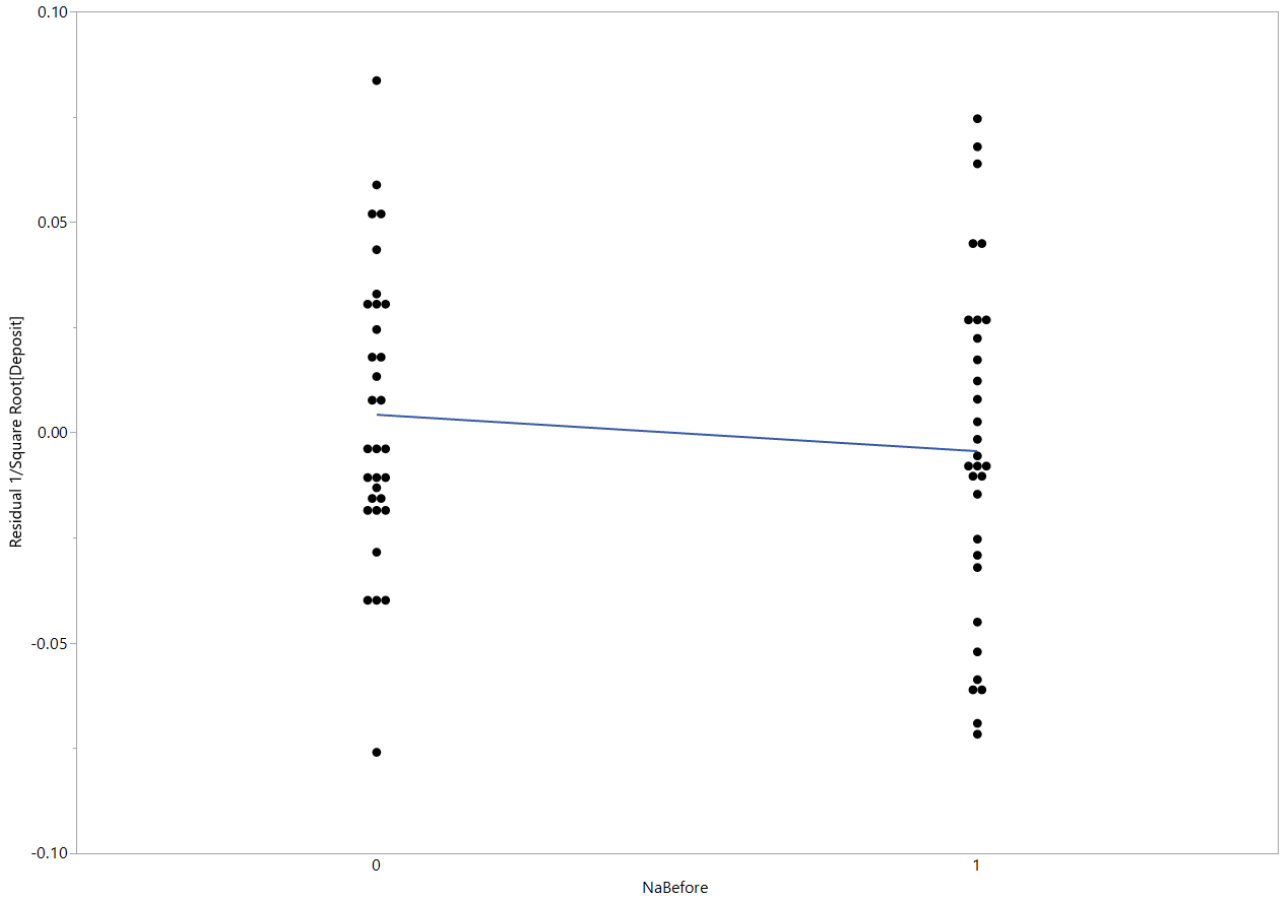
Operational Parameters
Speed, Fuel



No speed nor fuel parameter differences observed

Appendix B
Carry Over Effect

No significant carry over effect from Sodium

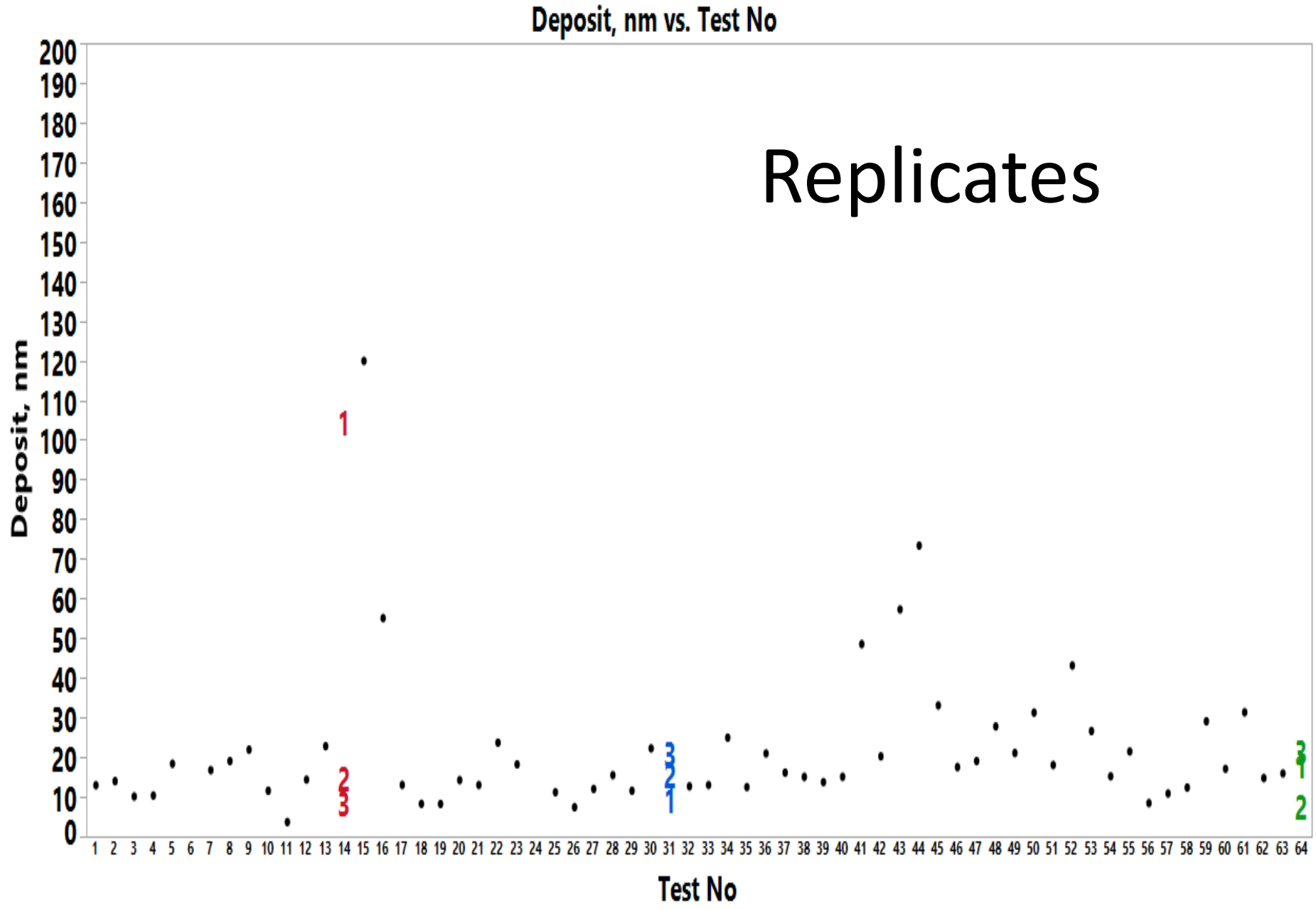


Fuel Research Using the Internal Diesel Injector Deposit (IDID) Rig (CRC Project No. DP-04-17) *Repeatability*

Jo Martinez

Mar. 19, 2019

Truncated



Replicates

Estimate of Standard Deviation

- RMSE from the ANOVA model with n=70

Summary of Fit

RSquare	0.676055
RSquare Adj	0.322661
Root Mean Square Error	0.06306
Mean of Response	0.241147
Observations (or Sum Wgts)	70

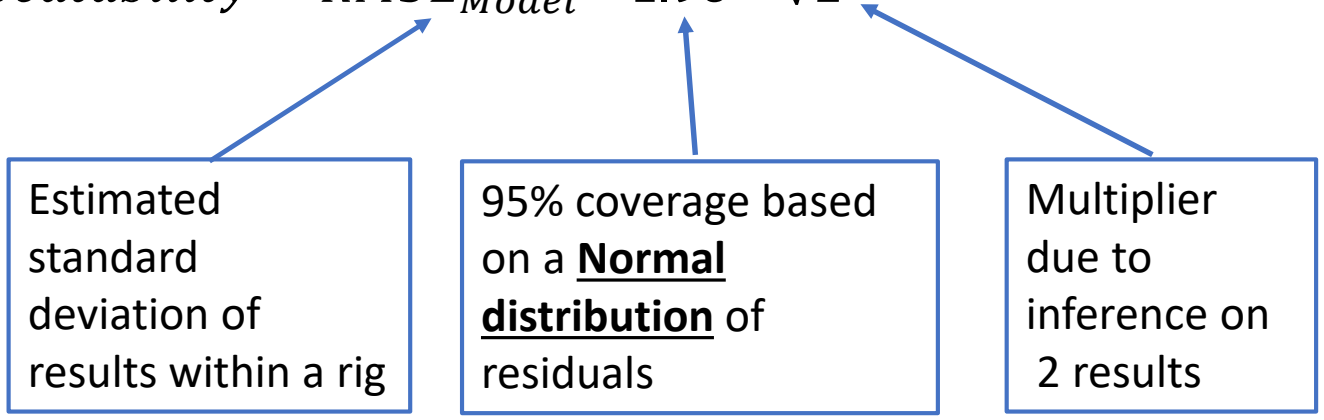
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	36	0.27386170	0.007607	1.9130
Error	33	0.13122599	0.003977	Prob > F
C. Total	69	0.40508769		0.0314*

Estimate of Repeatability

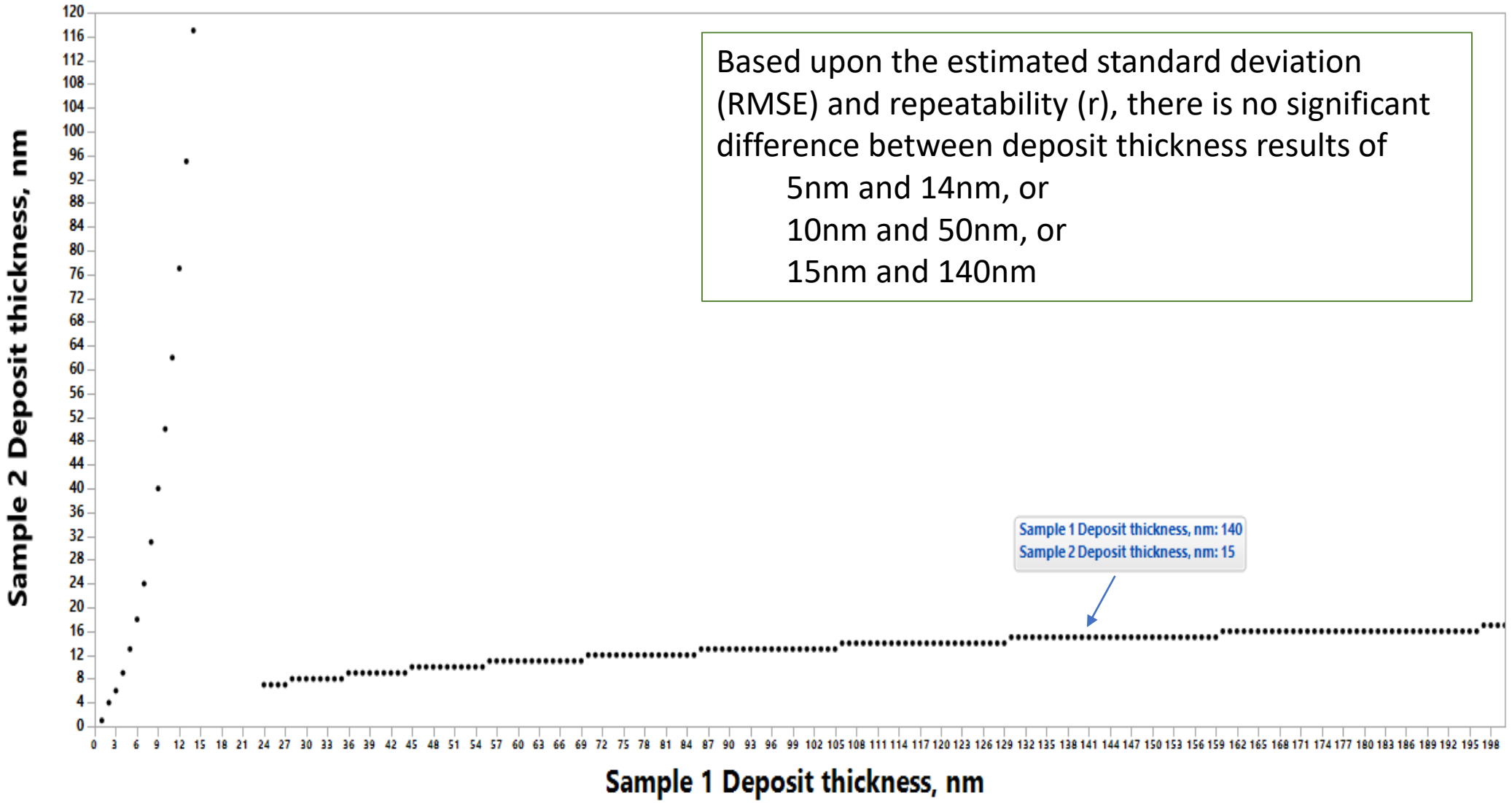
- Root Mean Square Error (RMSE) - estimate of standard deviation

$$Test_Repeatability = RMSE_{Model} * 1.96 * \sqrt{2}$$



- 1/sqrt(Deposit) Model RMSE = 0.0631
- Repeatability, r = 0.1748

Repeatability



Based upon the estimated standard deviation (RMSE) and repeatability (r), there is no significant difference between deposit thickness results of

5nm and 14nm, or

10nm and 50nm, or

15nm and 140nm

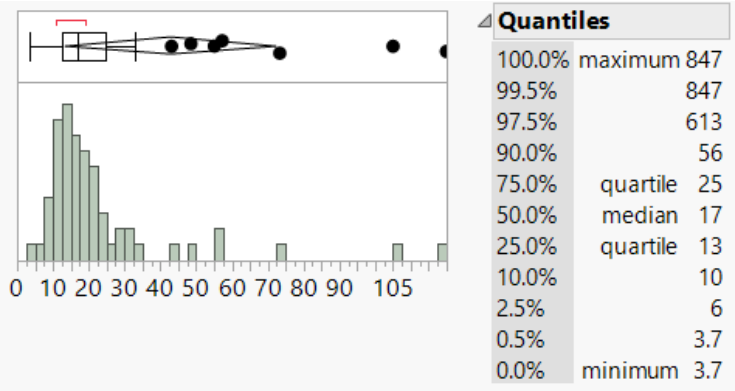
Appendix

Additional Testing Plan

Proposal for Additional Testing

Objective: To have a sense of repeatability of the test

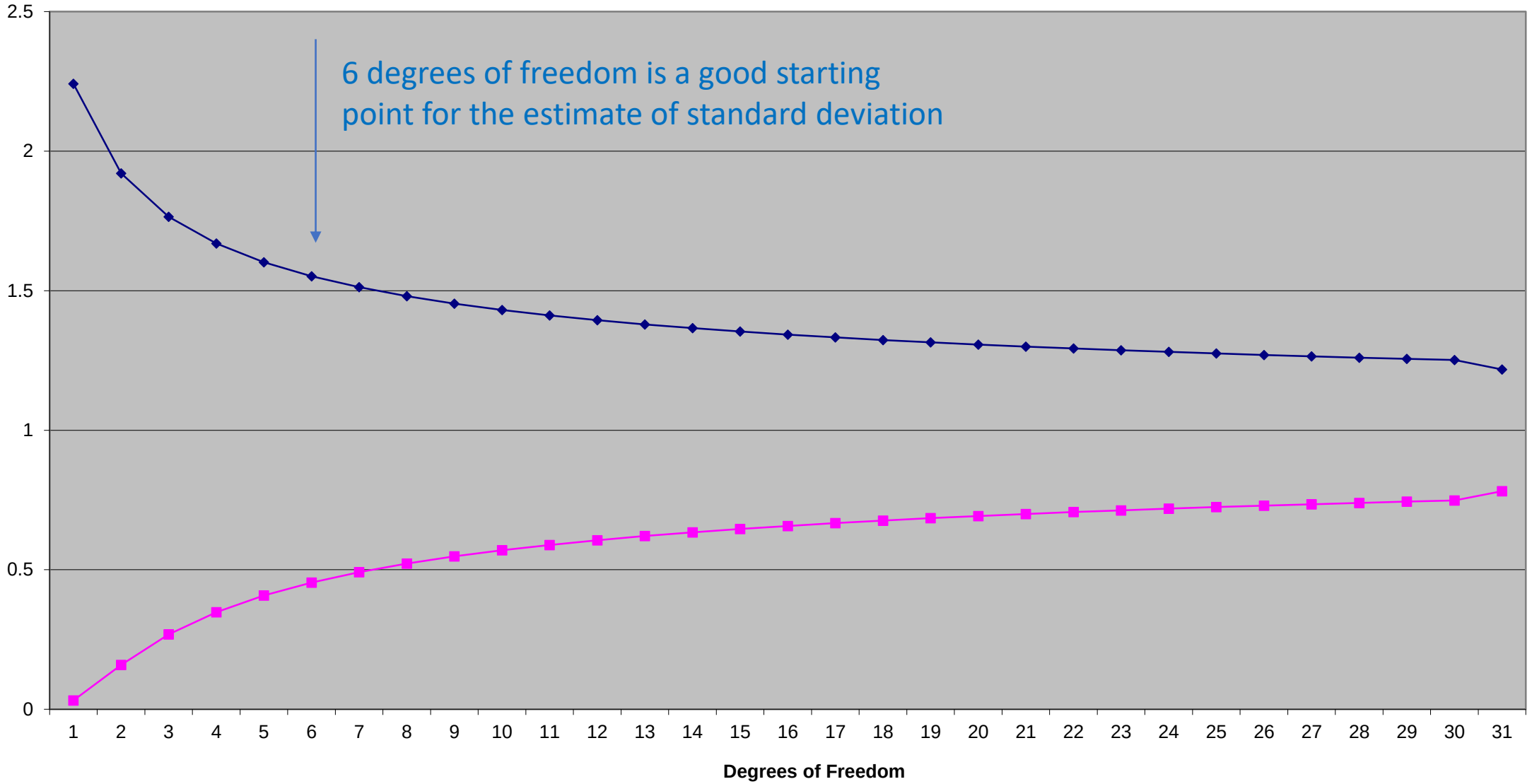
- 3 Fuels (tests no. 14, 31, 64)
  - Fuels chosen to span the range of deposits seen in the matrix
- 3 Replicates for each Fuel (1st replicate from the matrix)
- 6 error degrees of freedom to estimate standard deviation
- *Run 6 additional tests in designated run order*



Test No.	Matrix Result
31	10
64	19
14	105

Run Order	Test No.
1	14
2	31
3	64
4	64
5	31
6	14

Confidence Interval for Estimate of Standard Deviation



APPENDIX F

Rig Test Method

Test Method

Internal Diesel Injector Deposit (IDID) Test

[For Additional Information see Coordinating Research Council Report No. DP-04-17]

March 2019

Internal Diesel Injector Deposit (IDID) Test Method and Apparatus

1. Scope

This test method was designed to evaluate the relative internal diesel injector deposit (IDID) forming characteristics of compression ignition fuels and fuel/additive blends. The test is conducted under accelerated conditions and the results have not been shown to correlate to any specific period of normal engine operation. It is not applicable to evaluation of hardware effects, injection system design, or operating conditions. It is not specific to any high pressure common rail fuel injection system design. It is not applicable to recreation of injector nozzle hole deposits.

2. Summary of Test

Approximately 7-8 liters of test fuel are needed for this test. The apparatus is flushed with the test fuel prior to running the test. The test fuel flows through the injector apparatus at the prescribed flow rate, test duration and test temperature. At the conclusion of the test, the injector is removed and disassembled. The injector pintle is analyzed for deposits using an elipsometer.

3. Apparatus

a. **Injector Test Apparatus**

i. Hardware requirements:

Hartridge 2500 pump test stand or similar

Computerized Data Acquisition and Control System or similar

High Pressure Common Rail (HPCR) fuel injection pump capable of continuous operation at 1800 bar injection pressure

High Pressure Fuel Rail, compatible with 1800-bar pressure, with integrated pressure control valve and pressure transducer, GM 55496910 or equivalent

Injector heater block, as shown in Appendix, and 8 100W heater rods

Heat Sink Compound, manufactured by RS Supplies or similar Heat resistant tape, manufactured by RS Supplies or similar

6.35-mm round copper tab Type K thermocouples by RS Supplies or similar

Common Rail Diesel Fuel Injector and copper sealing washer, New Delphi Injector 28232248 or equivalent

Injector Driver with Variable Pulse Width Control Circuitry or ECM

Rail Pressure Controller with Variable Pulse Width Control Circuitry or ECM

ii. Test Rig Design:

A schematic diagram of the fuel delivery system layout is provided in Figure 1. The apparatus uses a high pressure common rail system, driven by a Hartridge 2500 pump test stand. The high pressure pump is operated at sufficient speed to generate the required pressure, typically 1750 rpm pump speed. Note the injection frequency and pump speed are decoupled, requiring a separate injector frequency generator.

The pump outlet is connected to a conventional rail, from which excess fuel is returned to the supply tank in the same way as on an operating vehicle. A fume extractor is used to ensure removal of any flammable vapors around the fuel tanks.

A high pressure pipe is connected from the rail to a single injector. The injection event is controlled by a variable width pulse to a custom peak and hold injector driver operating at a frequency of 12.5-Hz. The injection control as described is open loop, as there is not any feedback control on the injection quantity. Also connected to the fuel rail is a high pressure relief valve installed as a safety mechanism and set to vent 25% above the test operating pressure.

The injection pressure in the fuel rail is controlled by outlet metering using the rail pressure control valve and feedback from the rail pressure transducer. The rail pressure control valve is controlled by a variable width pulse operating at a frequency of 500-Hz. The Intake Control Valve (ICV) on the common rail pump is left disconnected so that the maximum rail pressure at each operating speed can be generated.

(An alternative approach may to be to use an ECM, appropriate control software, and dummy fuel injectors to mimic engine operation)

The single operating injector is clamped within a purpose made heater block. The heater block is subsequently bolted to a vessel that contains a cavity into which the fuel is injected, with a drain at the lowest point. The heater block contains a number of cartridge heater that simulate the combustion temperature present on an engine head. Eight 100 Watt cartridge heaters positioned around the heater block have been found to be sufficient.

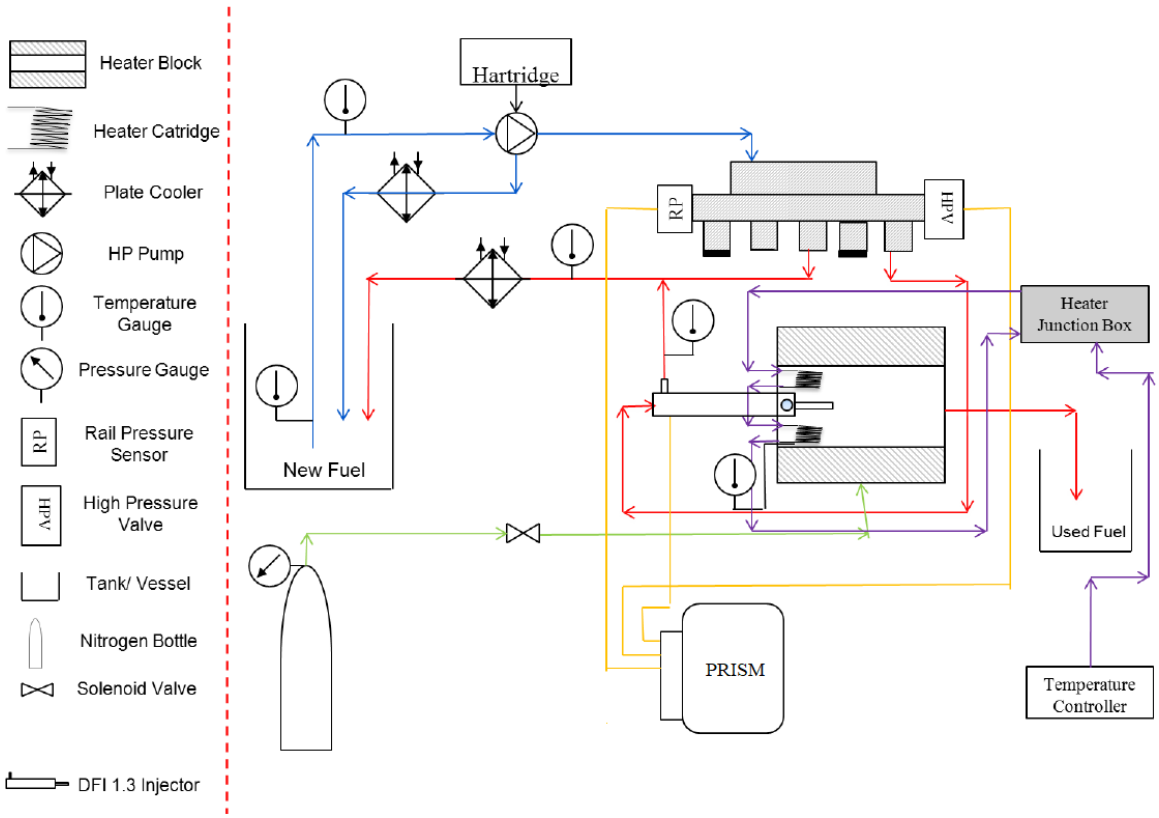


Figure 1. Test Rig Schematic Diagram

The injected fuel passes into the chamber attached to the heated block. This chamber is purged with nitrogen. Five second purges at 30 second intervals have been found to be sufficient. This purge process maintains an inert atmosphere within the test heater block and also serves to carry the injected fuel to a waste tank. The injected fuel is not returned to the main storage tank, as this fuel would normally be combusted on an operating engine. The main storage tank is mounted on a digital weighing scale to allow accurate real time measure of injected fuel flow rate throughout the test period.

The fuel return from the pump, rail and injector control valve (not injected fuel) passes through a heat exchanger which uses water plate coolers to cool down the fuel before returning it to the main storage tank. All tubing and pipework must be of sufficient diameter to prevent excessive back pressure. The materials used must be able to withstand the expected fuel temperatures, which can be up to 150ºC. Copper, zinc, or their alloys may not be used anywhere in the fuel system as this can have an effect on the deposit formed on the injector components.

Fuel filters are not used anywhere in the system. This is to facilitate easy cleaning. In addition, some metal carboxylate soaps are produced in the fuel tank and the resulting soap micelles may be removed by the fuel filter, resulting in filter plugging and inconsistent injector deposit results. As a result, great care must be taken to ensure cleanliness from

hard particulates while storing, transporting and blending test fuel. Ideally, the fuel should be filtered prior to placement in the system.

The injector temperature is measured using surface mount thermocouples mounted on the injector capnut, as shown in Figure 2. The second back-up thermocouple mounted at the appropriate location, has the capability to halt operation should an over-temperature event occur. Experience has shown that a fuel passage within the injector can affect the fuel temperatures measured at the capnut. It was determined the two capnut thermocouples should be mounted 45° off the centerline of the electrical connector on the injector. A conventional thermocouple within the heater block was also utilized for control and as a safety shutdown.

Temperature and pressure measurements are taken at appropriate locations on the system and the output recorded using an appropriate data acquisition system. Ideally, this system should have the ability to shut down the test if the measured temperature or pressure exceeds certain predetermined values or if a fuel leak occurs.

Figure 2: Photograph Showing Location of Surface Mount Thermocouple on Injector

b. **Deposit Measurement (VASE)**

Deposits on the surface of the pintle are measured using a Variable Angle Spectroscopic Ellipsometer (VASE). In order to properly utilize the VASE a new, clean pintle was scanned to build the baseline reflectance model.

4. Test Fuel

Prepare at least 7 liters of test fuel. The test fuel will be blended within 2 days prior to testing. When specific fuel additives or contaminants are part of the test fuel blend, the base fuel should be additive/contaminant free.

5. Test Conditions

The test operating conditions are given in Table 1.

Table 1. Test Operating Conditions

Test Parameter	Value	Units
Fuel Supply Temperature	30	°C
Cap Nut Temperature	200	°C
Rail Pressure	1800	Bar
Pump Speed	1750	RPM
Run Time	7	Hours
Injection Frequency	12.5	Hertz
Injected Volume	5	gram/minute
Fuel volume placed in tank (with rinse)	7	Liters
Fuel volume placed in tank (without rinse)	5	Liters

6. Injector Apparatus Operating Procedure

a. Remove thermocouples from an old injector, or use two new thermocouples, and place on the new injector using heat sink compound which acts as a conducting agent. Use the heat resistant tape to secure the thermocouples in place.

b. Place a copper washer onto the injector nozzle, and clamp the injector into the pressurized chamber by securing the clamp plates and cap head bolts.

c. Connect the High Pressure Fuel Supply Pipe, Fuel Return Pipe and Electrical Connector to the injector.

d. Check that all heater elements are fully fixed into the heater block. A view of a typical assembled heater block and injector assembly is provided in Figure 3.

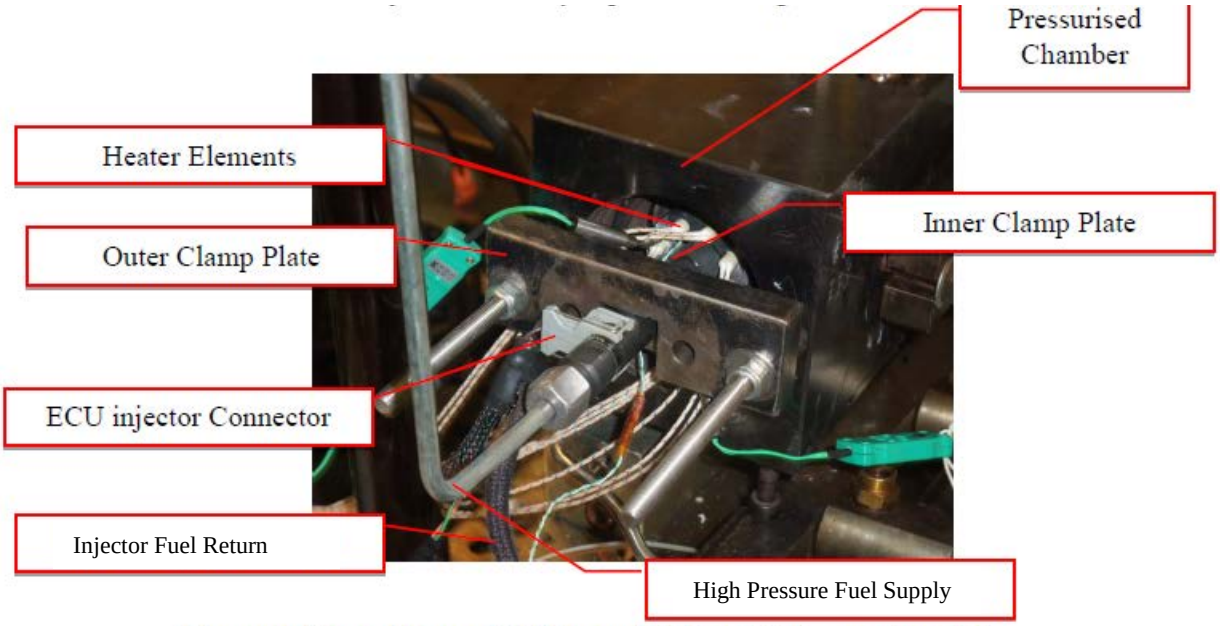


Figure 3: View of Assembled Heater Block and Injector Assembly

e. Blend sufficient fuel to allow rinse and subsequent testing. Typically 7L is found to be sufficient with a 2L rinse. Otherwise a separate fuel or solvent may be used for cleaning of the apparatus. Place the fuel in the storage tank and align the tank to position appropriately so that the feed and return pipe connections are in line.

f. The rinsing procedure will depend on the system design and the chemistry of the previous fuel used. Typically the control system should be programmed to slowly accelerate the rig to 500 RPM allow the existing fuel to be rinsed from the system and to fill with the new test fuel.

g. During this process, the rail and pump returns are temporarily fed into a separate container while the system is filled up with the new fuel batch. Approximately 2L of fuel is used to rinse the system into the separate container, leaving 5L in the storage tank. Following the cleaning procedure the return fuel pipe lines are replaced into the main fuel tank allowing the fuel to be recirculated for testing. Ensure the system is free of airlocks. After completion of the rinse, the rig speed is increased to the desired test speed.

h. Switch on the nitrogen purge system. Check that it is functional and that no leaks are occurring.

i. Switch on coolant for water plate cooler heat exchangers and return fuel coolers.

j. Slowly increase the pump speed. Ideally according to a predetermined ramp up procedure.

k. Set the required test temperature and cut-out temperature in case of malfunction on the heater controller.

l. Carefully check low pressure system for fuel leaks around the plate coolers or within the rig itself. Do not approach high pressure components.

m. Slight smoke may be seen from the heater block and is normal due to evaporation of fuel etc.

n. Smoke that persists for longer than 10 to 15 minutes may indicate a malfunction.

o. Turn on the vapor extractor for the rig and increase the rail pressure to 1800 bar.

p. Begin recording temperature and the other variables using appropriate data logging system.

q. The test apparatus should be carefully monitored for correct and safe operation regularly.

r. The injector pulse width may need be finely adjusted to ensure precise fuel flow after the system has reached operating temperature to ensure a fuel delivery of 5g/min has been achieved. Record mass difference in 5 minute or 10 minute intervals and work out fuel delivery using the mass difference and time frame. Keep doing this in the first hour until the correct pulse length is found to give a fuel delivery of 5g/min. Once complete let the test run normally for a period of 7 hours, keeping the pulse length unchanged from the 5g/min injection pulse length value.(open loop control of injection pulse width may require adjustment if flow deviates more than 5% from 5g/min)

s. The correct operation of the test stand should be monitored at regular intervals. In particular:

   i. Visually check for leaks, taking great care to avoid high pressure components

   ii. Ensure the fuel supply tank does not go below 0.5 litters

   iii. Record the fuel mass every hour for the entire duration of the test.

t. Log instrumented variables at 1Hz throughout test period.

7. Measurement of Deposits

Using Variable Angle Spectroscopic Ellipsometer (VASE) methodology, measure the deposit thickness in the desired region of the pintle. Example measurements are found in CRC Report No. DP-04-17.

8. Report

Report fuel blend information and measured deposit thickness results.