Electronic Supplementary Material (ESI) for Materials Advances.

SUPPORTING INFORMATION

Controlled synthesis of SPION@SiO_2 nanoparticles using design of experiments

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Key words: design of experiment; SPION, silica, core/shell; reverse microemulsion; DoE;

Supplementary Table S1: Synthesis treatments generated using a 3^3 full-factorial design, with the associated measured response variables including the silica shell thickness (t_{shell}), the monodispersity particles expressed as normalised entropy (E_n), and population of SPION@SiO_2 NPs.[1] Treatment 112 did not observe any SPION@SiO_2 NPs. Treatment 331 had an insufficient sample size to conduct entropy analysis. Treatment 222 was the centre point condition (CP), both the average results (222) and the five repeats (CP1-5) were displayed.

Experimental Factors					Response Variables						
Run	[TEOS] (mmol)	NH_4OH (mmol)	Frac. Add. TEOS	t_{shell} (nm)	σ	E_n	σ	Pop. (%)	σ	χ_m	σ
111	0.16	0.13	3	2	3	0.65	0.05	39	35	9.98	4.54E-03
112	0.16	0.13	6	N/A	N/A	N/A	N/A	N/A	N/A	2.98	3.63E-03
113	0.16	0.13	8	4	3	0.63	0.05	58	26	1.68	1.22E-03
121	0.16	0.65	3	7	3	0.47	0.06	35	9	1.81	2.74E-03
122	0.16	0.65	6	5	3	0.59	0.07	38	39	0.49	1.38E-03
123	0.16	0.65	8	11	3	0.33	0.02	61	11	1.20	3.63E-03
131	0.16	1.16	3	10	3	0.34	0.03	61	4	3.48	1.30E-03
132	0.16	1.16	6	12	3	0.31	0.02	64	11	4.05	8.77E-03
133	0.16	1.16	8	11	4	0.38	0.03	73	31	2.39	1.48E-03
211	1.42	0.13	3	24	4	0.22	0.03	45	8	0.20	8.47E-04
212	1.42	0.13	6	3	3	0.52	0.05	50	34	2.83	1.09E-03
213	1.42	0.13	8	10	3	0.42	0.03	98	11	2.15	3.37E-03
221	1.42	0.65	3	17	4	0.27	0.02	59	4	1.16	3.49E-04
222	1.42	0.65	6	15	6	0.30	0.06	48	32	0.96	3.40E-03
223	1.42	0.65	8	10	4	0.41	0.04	55	12	0.43	1.05E-03
231	1.42	1.16	3	10	3	0.38	0.03	81	2	9.17	1.71E-02
232	1.42	1.16	6	23	3	0.20	0.01	69	5	0.64	4.99E-04
233	1.42	1.16	8	21	3	0.15	0.02	51	13	0.71	1.21E-03
311	2.69	0.13	3	13	3	0.28	0.01	85	5	2.04	1.00E-03
312	2.69	0.13	6	12	3	0.32	0.03	99	1	3.49	7.49E-03
313	2.69	0.13	8	3	3	0.50	0.05	52	39	2.65	2.37E-03

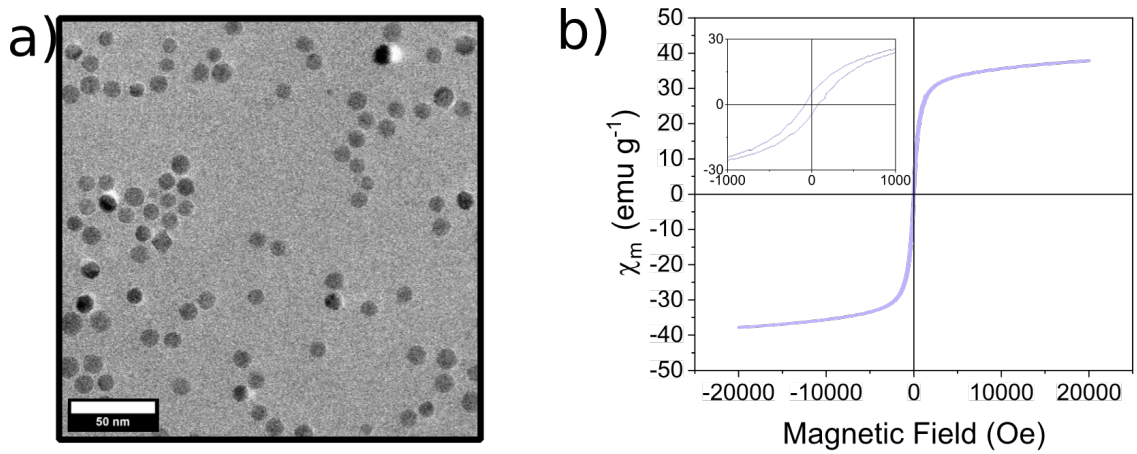
Table 1 continued from previous page

321	2.69	0.65	3	21	4	0.28	0.03	39	10	0.19	1.40E-03
322	2.69	0.65	6	20	3	0.19	0.01	53	4	0.53	5.14E-04
323	2.69	0.65	8	25	3	0.19	0.02	37	2	0.36	1.20E-03
331	2.69	1.16	3	19	3	N/A	N/A	2	6	0.29	3.23E-04
332	2.69	1.16	6	27	4	0.23	0.03	37	11	0.31	9.58E-04
333	2.69	1.16	8	32	4	0.15	0.01	67	2	0.26	2.67E-04
CP1	1.42	0.65	6	15	3	0.29	0.03	51	6	1.08	1.07E-03
CP2	1.42	0.65	6	16	3	0.25	0.03	47	15	0.71	1.13E-03
CP3	1.42	0.65	6	11	3	0.38	0.04	43	19	1.66	2.74E-03
CP4	1.42	0.65	6	18	3	0.22	0.01	49	14	0.81	5.56E-04
CP5	1.42	0.65	6	16	4	0.33	0.03	49	15	0.52	1.15E-03

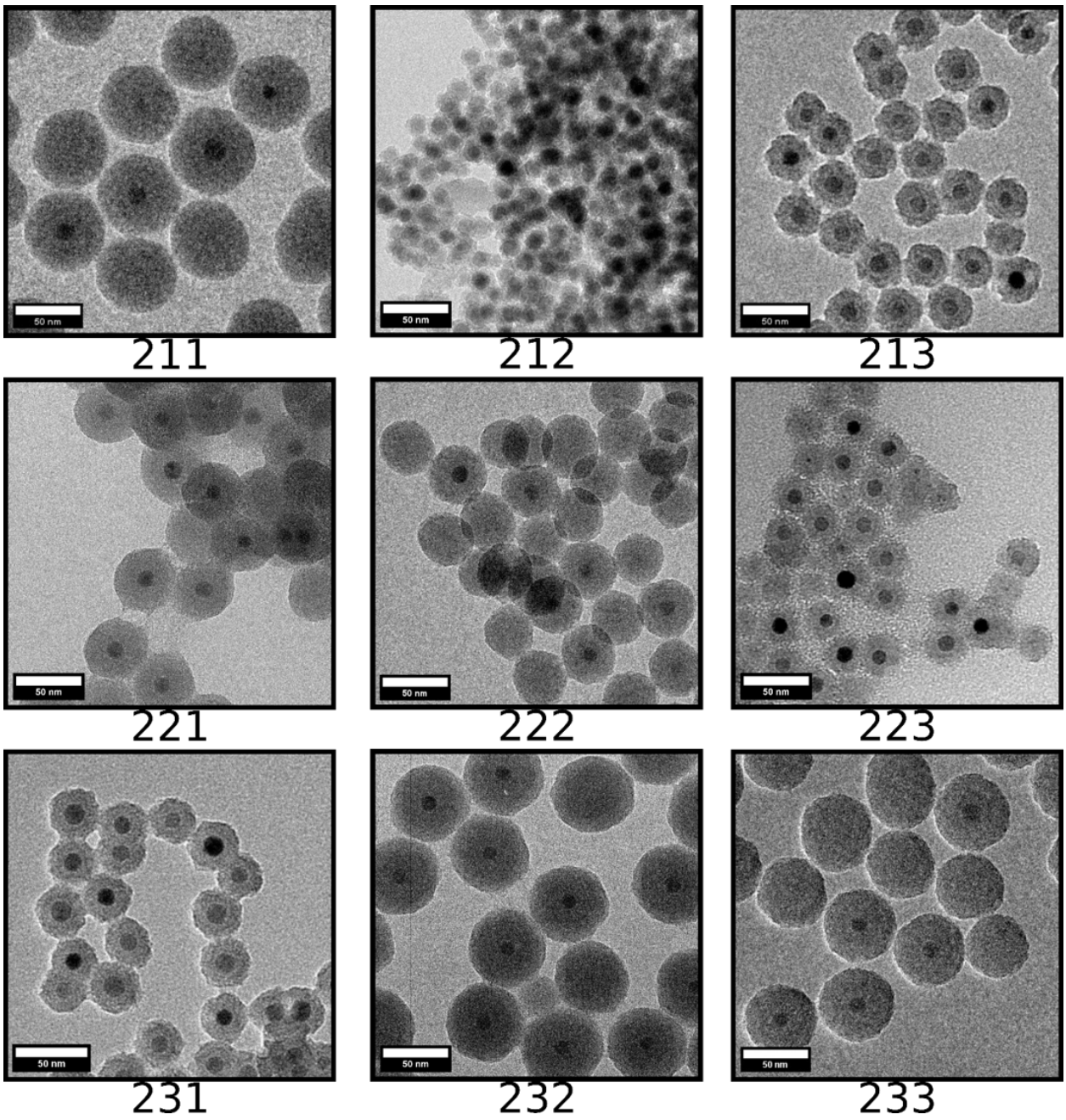
Supplementary Table S2: Lack of fit test for the population of SPION@SiO_2 formed demonstrating that there is a high experimental error (pure error).

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	5	1688.98	337.80	0.93
Pure Error	22	7997.69	363.53	p-value
Total Error	27	9686.67		0.48
				Max RSq
				0.44

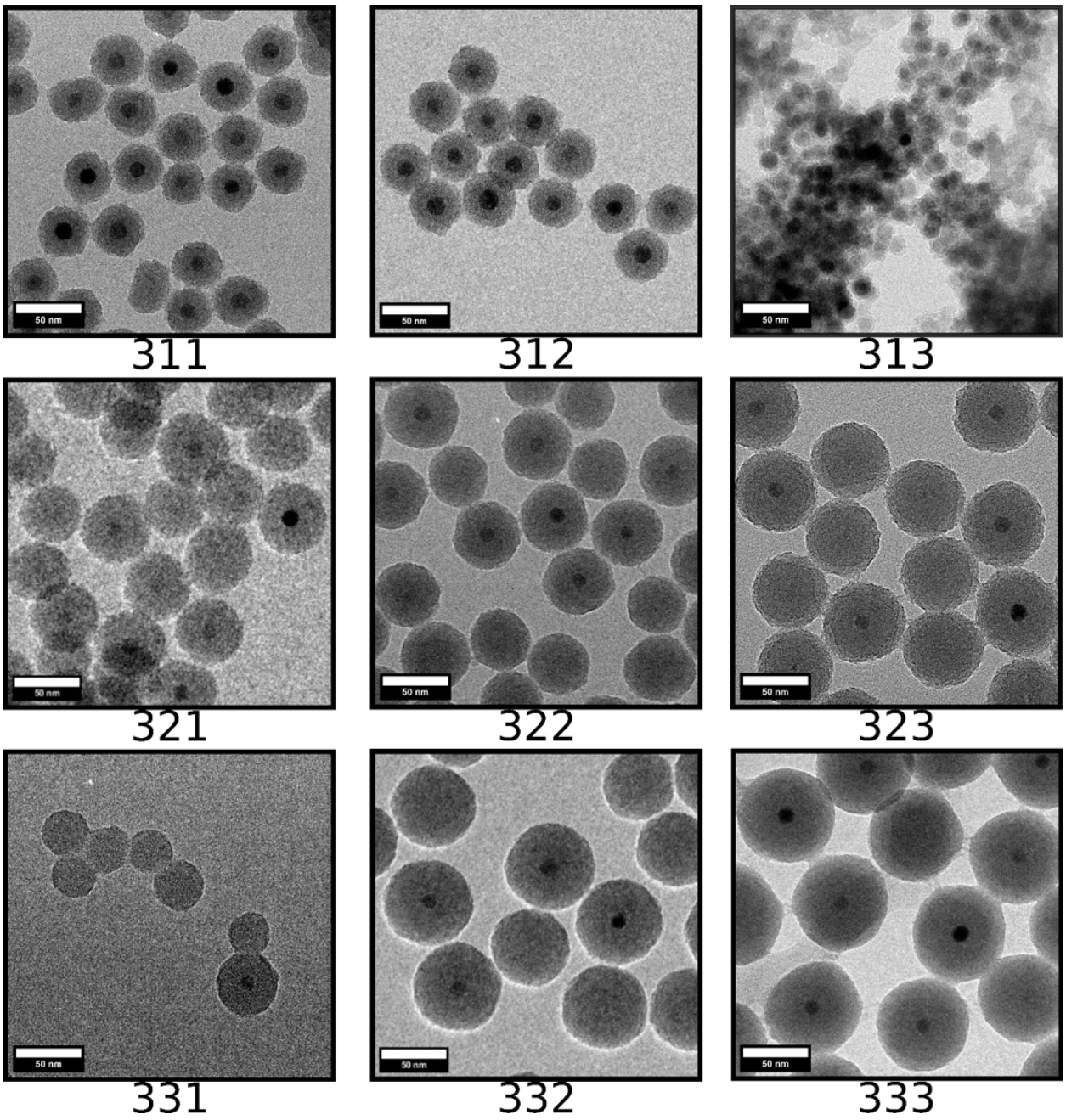
The lack of fit is the model error, the pure error is experimental error, total error is the sum of the model and experimental error. The sum of squares is the total error for each error source (model, experimental, total). Mean square is the total error for each source, adjusted by the degree of freedom (DF) for each source. The F-ratio is given by the ratio of mean square of lack of fit by the pure error.



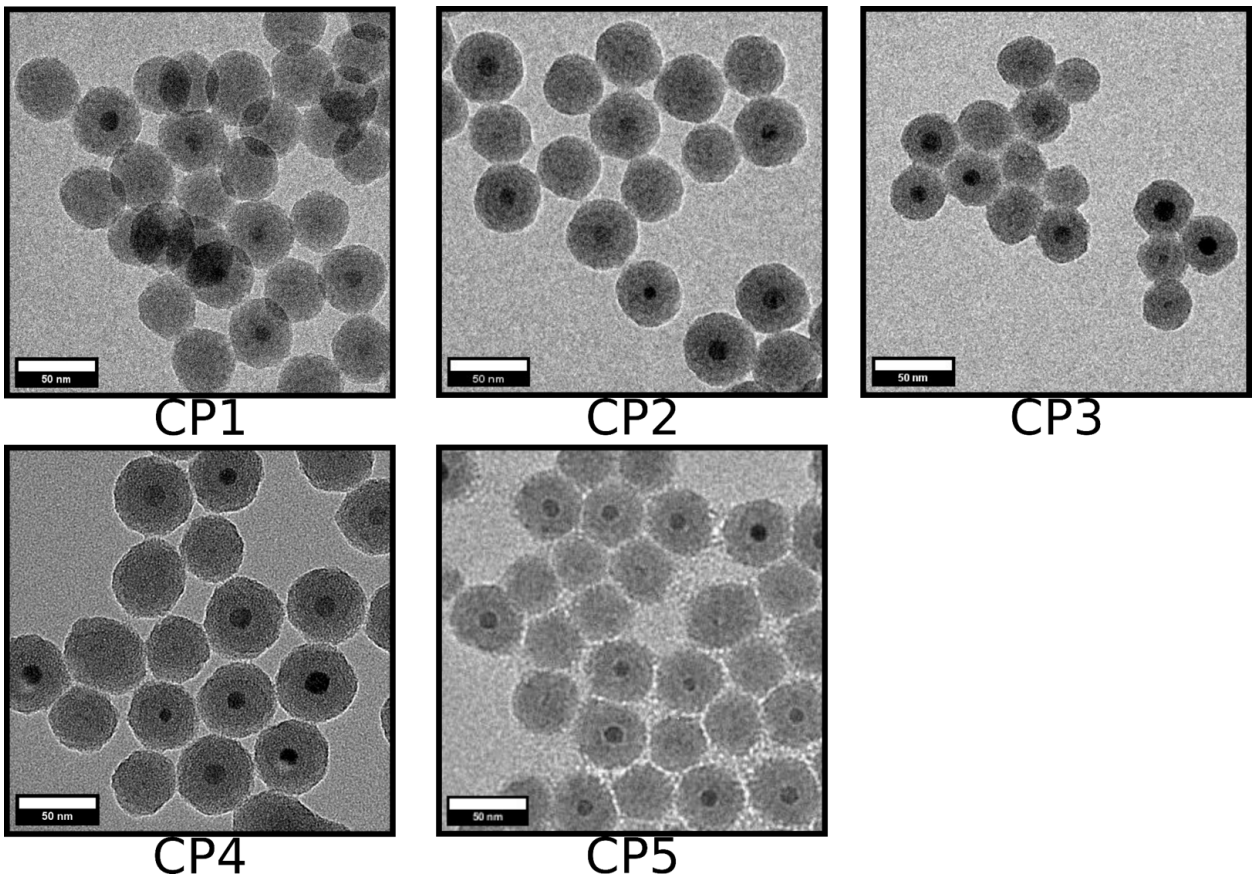
Supplementary Figure S1: TEM and χ_m characterisation of SPION produced using the thermal decomposition method. Where a) TEM image of SPIONs with size of 13 $\pm$ 1 nm b) Graph of magnetic behaviour of SPION with with a χ_m of 38 emu g^{-1} at 20,000 Oe.



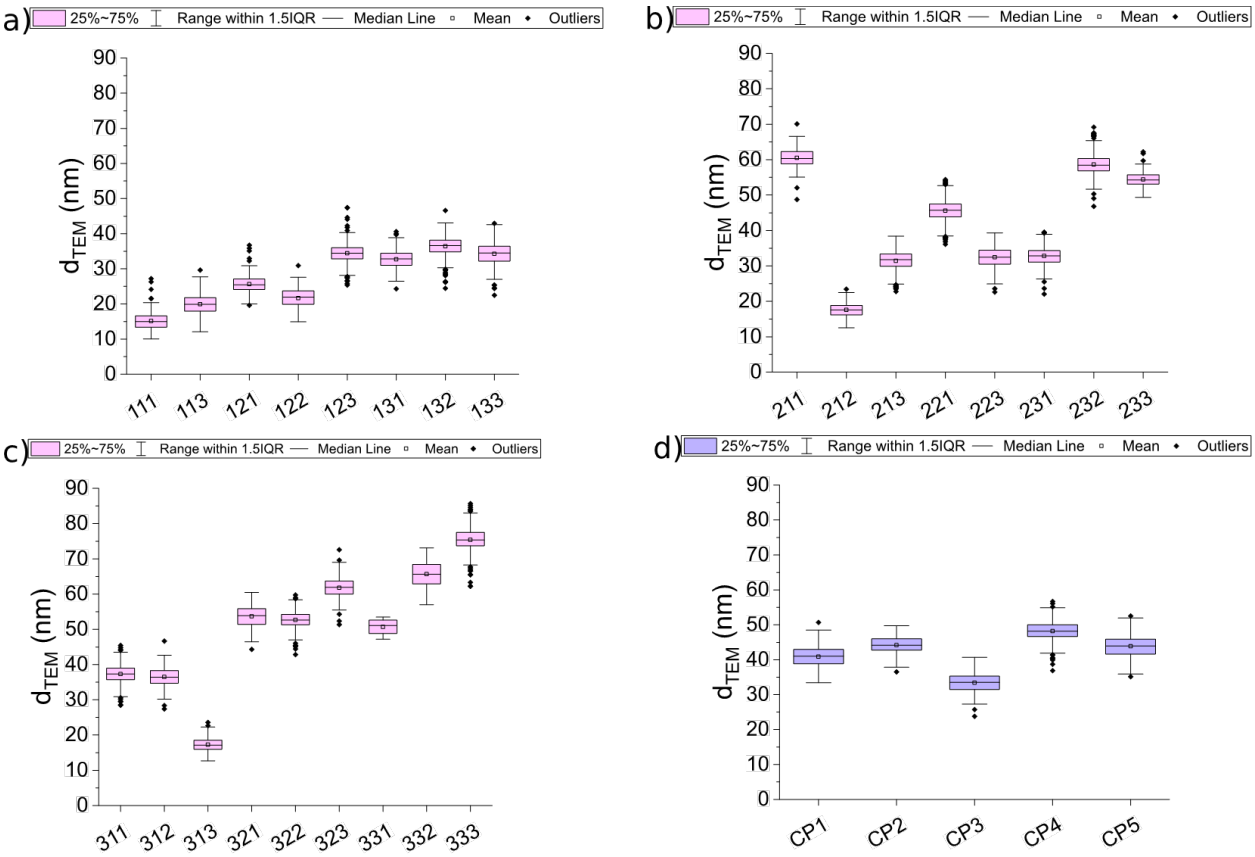
Supplementary Figure S 2: TEM images of SPION@SiO_2 NPs produced using conditions determined from the 3^3 factorial, at level 2 number of moles of TEOS (1.42 mmol). The x-axis (row) is increasing from left to right in levels of fractionated additions of TEOS, from levels 1 to 3. The y-axis (column) is increasing from top to bottom in levels 1 to 3 for the concentration of NH_4OH. The z-axis is the concentration of TEOS. Each 3 digit code is the xyz coordinates for each treatment condition generated from the experimental domain.



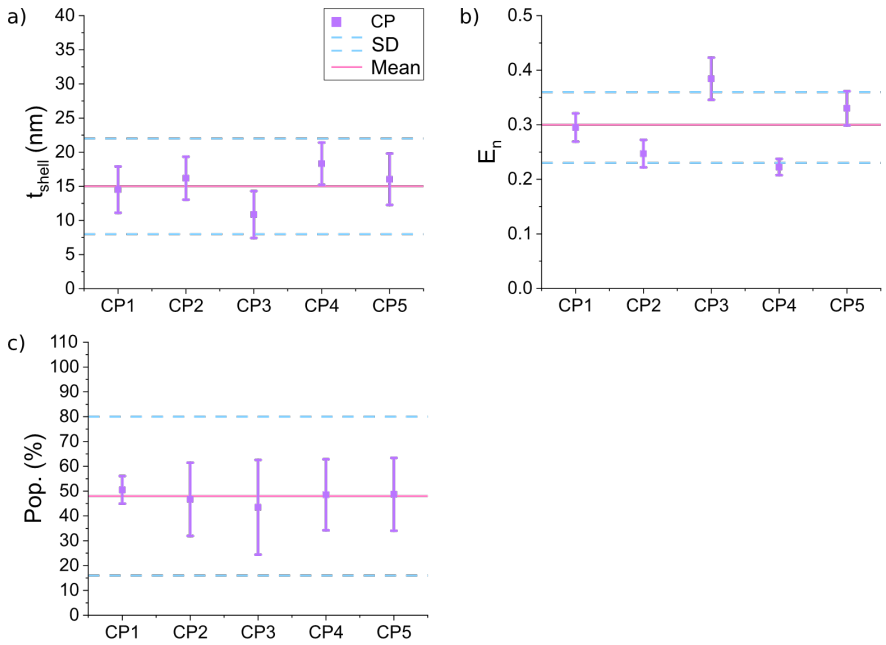
Supplementary Figure S 3: TEM images of SPION@SiO_2 NPs produced using conditions determined from the 3^3 factorial, at level 3 of the concentration of TEOS (2.69 mmol). The x-axis (row) is increasing from left to right in levels of fractionated additions of TEOS, from levels 1 to 3. The y-axis (column) is increasing from top to bottom in levels 1 to 3 for the concentration of NH_4OH. The z-axis is the concentration of TEOS. Each 3 digit code is the xyz coordinates for each treatment condition generated from the experimental domain.



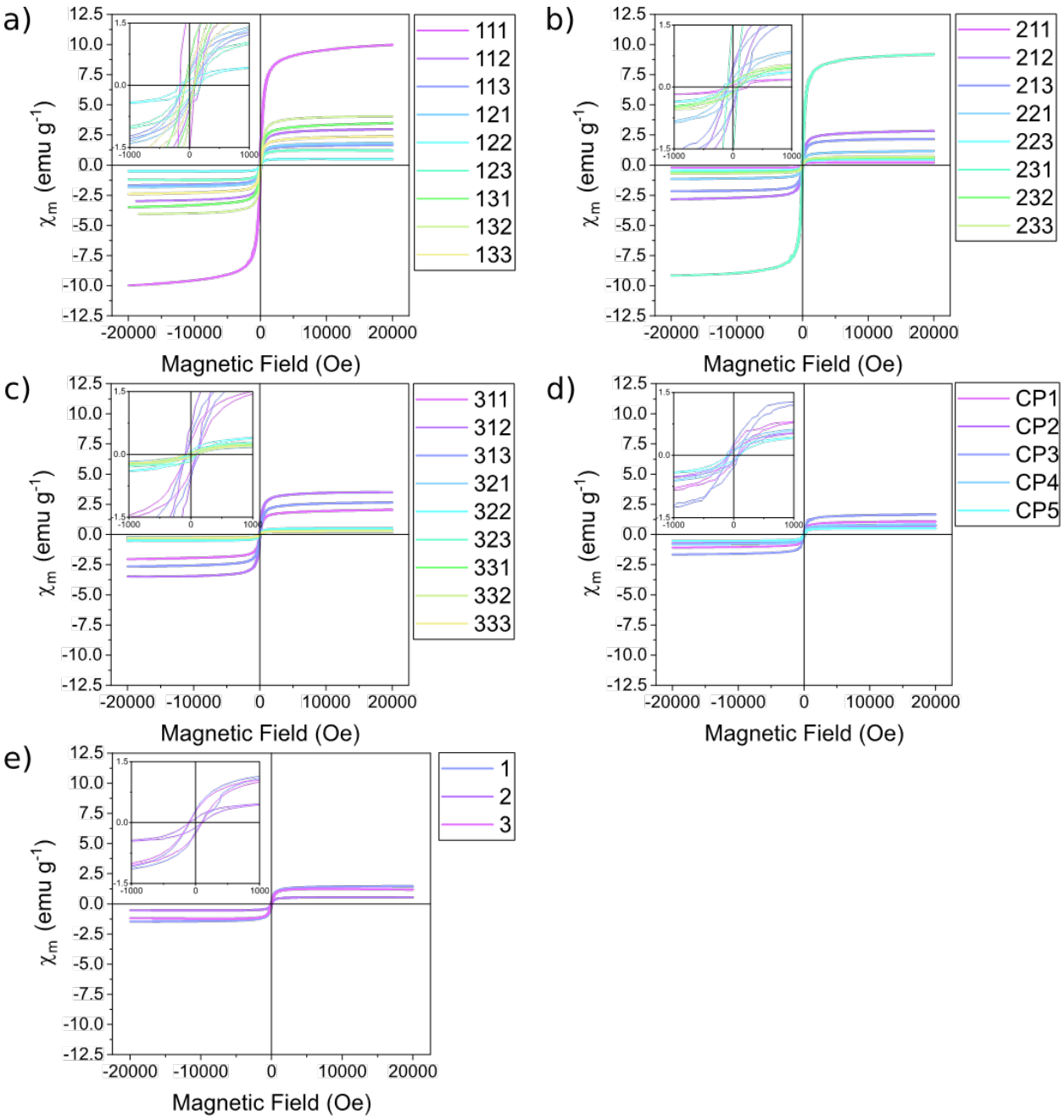
Supplementary Figure S 4: TEM images of SPION@SiO_2 NPs produced using treatment conditions 222, the centre point condition (CP), determined from the 3^3 factorial model.



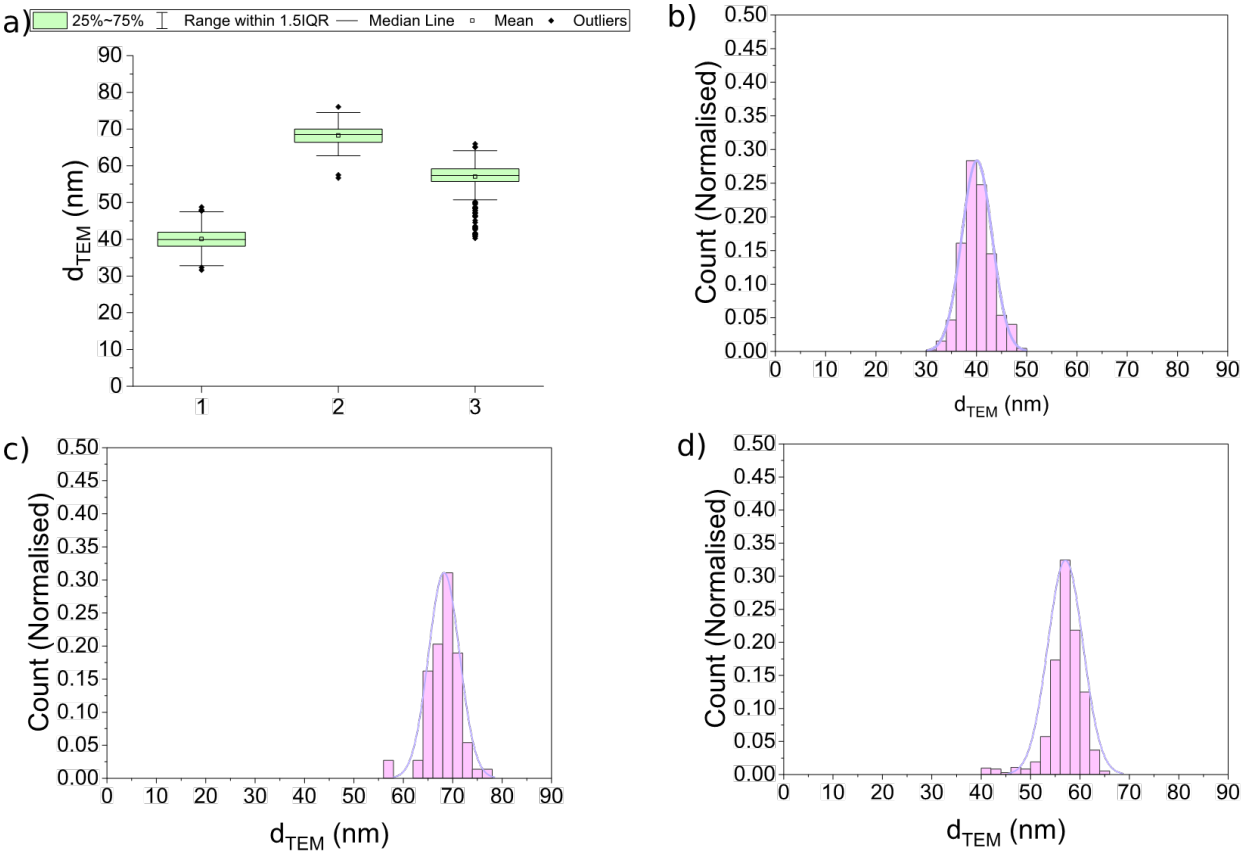
Supplementary Figure S5: Box-plot of the diameter measured from TEM images, d_{TEM}, of the treatments used. a) d_{TEM} of level 1 of concentration of TEOS b) d_{TEM} of level 2 of concentration of TEOS c) d_{TEM} of level 3 of concentration of TEOS d) d_{TEM} of level of centre point conditions, 222. Note 112 did not form any measurable SPION@SiO_2. The centre point condition was repeated 5 times, and hence, not included in figure b.



Supplementary Figure S 6: Scatter plot of centre point (CP) repeat using treatment 222, for each response variable. Purple squares are the response values, the pink line is the mean response, and the dashed blue line is the sum of errors for each response. Note that the error bars for the t_{shell} and E_n is the standard deviation for each sample. The error bar for population is calculated from the deviation of population of core@shells measured per TEM image. Here a) t_{shell} b) E_n c) population.



Supplementary Figure S7: Mass susceptibility χ_m characterisation of all treatments and centre point conditions used in the 3^3 full factorial design. a) χ_m at Level 1 number of moles of TEOS b) χ_m at Level 2 number of moles of TEOS c) χ_m at Level 3 number of moles of TEOS d) χ_m at treatment 222, centre point (CP) e) χ_m of validation runs 1 to 3. χ_m can be seen in Table 1



Supplementary Figure S 8: Size distribution of SPION@SiO_2 NPs produced using validation conditions. a) Box-plot of d_{TEM} b) d_{TEM} histogram of run 1 c) d_{TEM} histogram of run 2 d) d_{TEM} histogram of run 3

Bibliography

[1] N. Mac Fhionnlaoich and S. Guldin, *Chemistry of Materials*, 2020, **32**, 3701–3706.