Integrated Coagulation–Disinfection Using Aluminium Polychloride and Sodium Hypochlorite for Secondary Wastewater Treatment: Operational Advantages and DBP Mitigation

Table S1. Summary of the experimental design for the preliminary batch experiment

Series. n	NaClO dose (mg/L)	PACl dose (mg/L)	Treatment method	Process time	Outcome
1	0	0,1.5, 3, 4.5, 6, 13.5	Coagulation	60 min (mixing + settling)	Total phosphorus
2	5	0,1.5, 3, 4.5, 6, 13.5	Simultaneous coagulation/disinfection	60 min (mixing + settling)	Total phosphorus
3	3	0,3,6	Simultaneous coagulation/disinfection	30 min mixing	Soluble phosphorus, Total coliform
4	3	0,3,6	Sequential coagulation — disinfection	30 min — 30 min mixing	Soluble phosphorus, Total coliform
5	3	0,3,6	Sequential disinfection — coagulation	30 min — 30 min mixing	Soluble phosphorus, Total coliform

Table S2. Soluble phosphorous concentrations using various NaClO and PACl doses

NaClO Conc ***(mg/L)***	**PACl Conc** ***(mg/L)***	**Soluble P** ***(mg/L)***					
		Day 1	*Day 2*	*Day 3*	*Day 4*	*Day 5*	*Average*
3	0	0.19	0.21	0.31	0.33	0.31	0.26
4.5	0	0.19	0.21	0.35	0.33	0.33	0.282
6	0	0.19	0.21	0.38	0.28	0.33	0.278
3	3	0.11	0.16	0.14	0.13	0.16	0.14
4.5	4.5	0.13	0.16	0.15	0.1	0.15	0.138
6	6	0.15	0.12	0.13	0.11	0.15	0.132
3	6	0.13	0.14	0.14	0.11	0.13	0.13
4.5	9	0.11	0.13	0.15	0.15	0.17	0.142

6	12	0.16	0.12	0.14	0.1	0.12	0.128

Table S3: Total and fecal coliform inactivation and DBP s formation using various NaClO and PACl doses, during different mixing time over bench scale testing

NaClO Conc *(mg/L)*	**PACl Conc** *(mg/L)*	**Mixing time** *(S)*	**Fecal Coliform** *(CFU/100 mL)*	**Total Coliform** *(CFU/100 mL)*	**THMs** *(µg/L)*	**HAAs** *(µg/L)*	**HALs** *(µg/L)*	**HKs** *(µg/L)*
3	0	29	5.80E+02	1.19E+04	8.95	21.04	7.3	6.9
3	3	29	2.00E+02	1.47E+03	3.9	18.75	4.9	6.7
3	6	29	1.70E+02	7.90E+02	3.9	17.2	2.8	6.5
4.5	0	29	2.80E+02	1.50E+04	15.25	19.65	5	6.9
4.5	4.5	29	5.20E+01	1.10E+02	8	19.95	2.8	6.7
4.5	0	29	5.00E+01	3.00E+02	8	20.75	7.1	6.7
6	0	29	8.00E+00	3.20E+01	4.1	20.75	7.2	7.1
6	6	29	9.00E+00	2.00E+01	12.4	20.7	2.8	6.9
6	12	29	1.60E+01	3.40E+01	6.1	19.7	2.8	6.9
3	0	21	1.30E+02	1.54E+03	8.9	16.55	7.4	7
3	3	21	6.00E+01	8.20E+02	12.85	28.1	7.1	6.9
3	6	21	1.00E+02	5.60E+02	13	16.3	7.1	7
4.5	0	21	1.00E+02	5.10E+02	8.8	17.95	7	6.9
4.5	4.5	21	7.60E+01	7.90E+02	13.05	19.9	7.1	7
4.5	0	21	1.60E+01	1.60E+02	12.8	16.7	6.9	6.8
6	0	21	1.20E+01	1.00E+02	9.4	36.7	7.3	7.2
6	6	21	2.90E+01	2.80E+02	13.85	37.45	7.5	7.5
6	12	21	2.10E+01	1.50E+02	13.4	21	7.1	7.3
3	0	14	3.50E+02	2.30E+03	3.85	16.15	7	6.8
3	3	14	2.90E+02	2.00E+03	8	18.75	6.8	6.7
3	6	14	1.60E+02	1.30E+03	8	17.1	7	6.6
4.5	0	14	3.20E+01	6.90E+02	4	18.55	7.3	7.1
4.5	4.5	14	1.60E+02	5.40E+02	19.4	23.65	7.4	7.1
4.5	0	14	5.70E+01	4.00E+02	14.7	26.45	7.2	6.9
6	0	14	7.90E+01	5.60E+02	15.9	15.5	7.6	7.4
6	6	14	2.50E+01	2.00E+02	19.35	24.35	7.4	7.1

6	12	14	2.10E+01	3.00E+02	19.05	23.75	7.3	7

Table S4. Total and fecal coliform inactivation using various NaClO and PACl doses, and various wastewater flowrate over pilot scale testing

NaClO Conc ***(mg/L)***	**PACl Conc** ***(mg/L)***	**Wastewater Flow Rate** ***(L/hr)***	**Fecal Coliform** ***(CFU/100 mL)***	**Total Coliform** ***(CFU/100 mL)***
3	0	3.7	1.20E+01	6.50E+02
3	3	3.7	8.00E+00	2.80E+01
3	6	3.7	8.00E+00	3.00E+01
4.5	0	3.7	1.00E+00	1.00E+00
4.5	4.5	3.7	6.00E+00	2.20E+01
4.5	0	3.7	5.00E+00	2.10E+01
6	0	3.7	2.00E+00	2.00E+00
6	6	3.7	6.00E+00	1.20E+01
6	12	3.7	4.00E+00	9.00E+00
3	0	8	1.20E+01	1.90E+02
3	3	8	1.00E+01	5.40E+01
3	6	8	1.00E+01	3.60E+01
4.5	0	8	3.50E+01	1.10E+02
4.5	4.5	8	8.00E+00	3.80E+01
4.5	0	8	3.00E+00	4.00E+01
6	0	8	7.00E+00	1.26E+02
6	6	8	5.00E+00	1.80E+01
6	12	8	3.00E+00	1.10E+01
3	0	12	8.00E+00	3.00E+01
3	3	12	1.00E+00	1.20E+01
3	6	12	6.00E+00	3.80E+01
4.5	0	12	2.50E+01	9.00E+01
4.5	4.5	12	6.00E+00	3.20E+01
4.5	0	12	3.00E+00	1.80E+01
6	0	12	9.00E+00	4.60E+01
6	6	12	6.00E+00	2.80E+01

6	12	12	5.00E+00	1.80E+01

Table S5. DBPs formation using various NaClO and PACl doses, and various wastewater flowrate over pilot scale testing

NaClO Conc *(mg/L)*	**PACl Conc** *(mg/L)*	**Wastewater Flow Rate** *(L/hr)*	**THMs** *(µg/L)*	**HAAs** *(µg/L)*	**AOX** (µg/L)	**HANs** (µg/L)	**HALs** *(µg/L)*	**HKs** *(µg/L)*
3	0	3.7	16.25	29.6	218.7	4.5	9.8	9.4
3	3	3.7	16.15	26.25	223.5	4.2	9.2	8.7
3	6	3.7	15.65	24.8	173.6	3.9	9	8.5
4.5	0	3.7	15.65	33.3	417	4.3	8.9	9.2
4.5	4.5	3.7	15.5	26.95	161.8	4.2	9.1	8.9
4.5	0	3.7	15.7	27.1	158.6	4.1	8.9	8.6
6	0	3.7	17.1	27.3	212.3	4.3	9.1	8.9
6	6	3.7	17.35	32.45	156.9	4.6	9.6	10.9
6	12	3.7	16.5	25	183.8	4.3	9.5	9.2
3	0	8	13.65	19.35	139.5	1.9	7.7	7.5
3	3	8	13.5	18.5	133.8	2	7.4	7.1
3	6	8	13.7	18.65	132.2	1.8	7.2	7.1
4.5	0	8	13.95	20.4	135.2	2	7.8	7.6
4.5	4.5	8	14.4	19.3	146.8	2	7.9	7.5
4.5	0	8	13.9	18.75	274.5	2	13.5	7.6
6	0	8	14.25	20.9	185.8	2.9	8.1	7.8
6	6	8	13.7	19.75	161.8	2.9	8.1	7.7
6	12	8	14.3	19.8	157.4	3.7	8.2	7.9
3	0	12	20.25	19.05	147.9		7.5	7
3	3	12	15.05	20.3	161.6	2	7.5	7
3	6	12	19.2	18.3	225.4		7.4	7
4.5	0	12	20.05	18.35	233.7	1.9	7.7	7.2
4.5	4.5	12	19.45	17.65	202.8	1.6	7.8	7.2
4.5	0	12	19.45	17.5	217.3	2.1	7.8	7.2
6	0	12	20.6	34	226.9	3.6	8.6	8.1
6	6	12	20.8	34.65	234.7	2.1	8.3	7.6

6	12	12	15.05	16.75	230.2	2.1	7.8	7.3

Table S6. List of monitored DBPs.

Trihalomethanes (THMs)	**Haloacetonitriles (HANs)**
Trichloromethane (TCM)	Trichloroacetonitrile (TCAN)
Bromodichloromethane (BDCM)	Dichloroacetonitrile (DCAN)
Dibromochloromethane (DBCM)	Bromochloroacetonitrile (BCAN)
Tribromomethane (TBM)	Dibromoacetonitrile (DBAN)

Haloacetic Acids (HAAs)		**Haloketones (HKs)**
Chloroacetic acid (MCAA)	Bromodichloroacetic acid (BDCAA)	1,1-Dichloropropanone (DCP)
Dichloroacetic acid (DCAA)	Chlorodibromoacetic acid (CDBAA)	1,1,3-Trichloropropanone (TCP)
Trichloroacetic acid (TCAA)	Dibromoacetic acid (DBAA)	
Bromoacetic acid (MBAA)	Tribromoacetic acid (TBAA)	
Bromochloroacetic acid (BCAA)		

Haloacetaldehydes (HALs)	**Other**
Dichloroacetaldehyde (DCAL)	Adsorbable Organohalides (AOX)
Trichloroacetaldehyde (TCAL)	
Tribromoacetaldehyde (TBAL)	

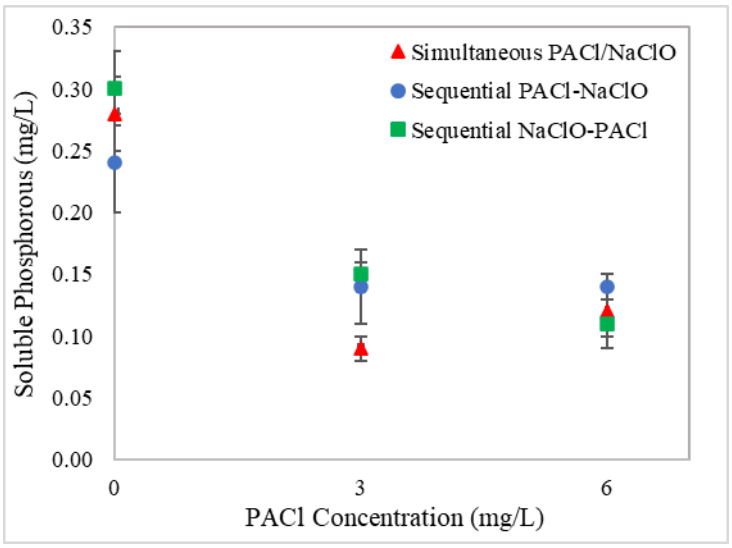

Figure S1. Soluble phosphorus removal as a function of different PACl doses.

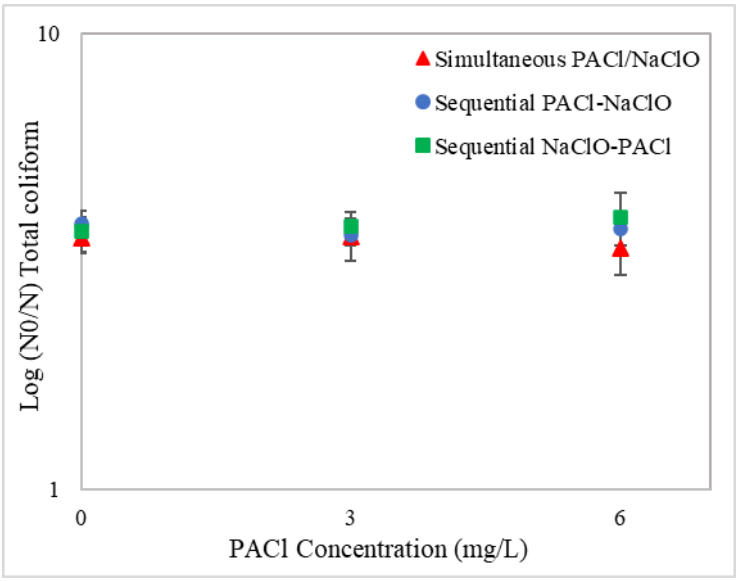

Figure S2. Normalized concentration (N/N_0) of total coliform over different PACl doses.

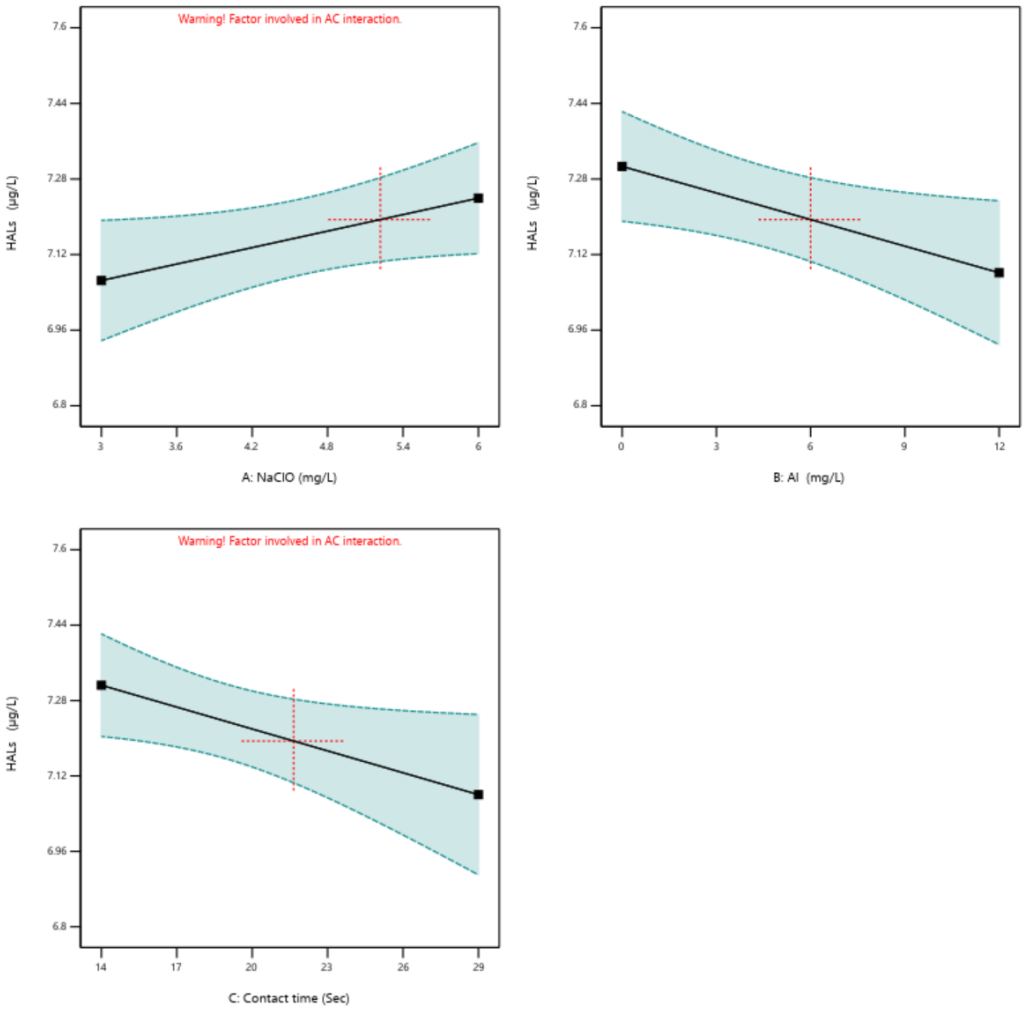

Figure S3. Profile plots of HAL formation; Panel A: NaClO dose, Panel B: PACl dose, Panel C: contact time.

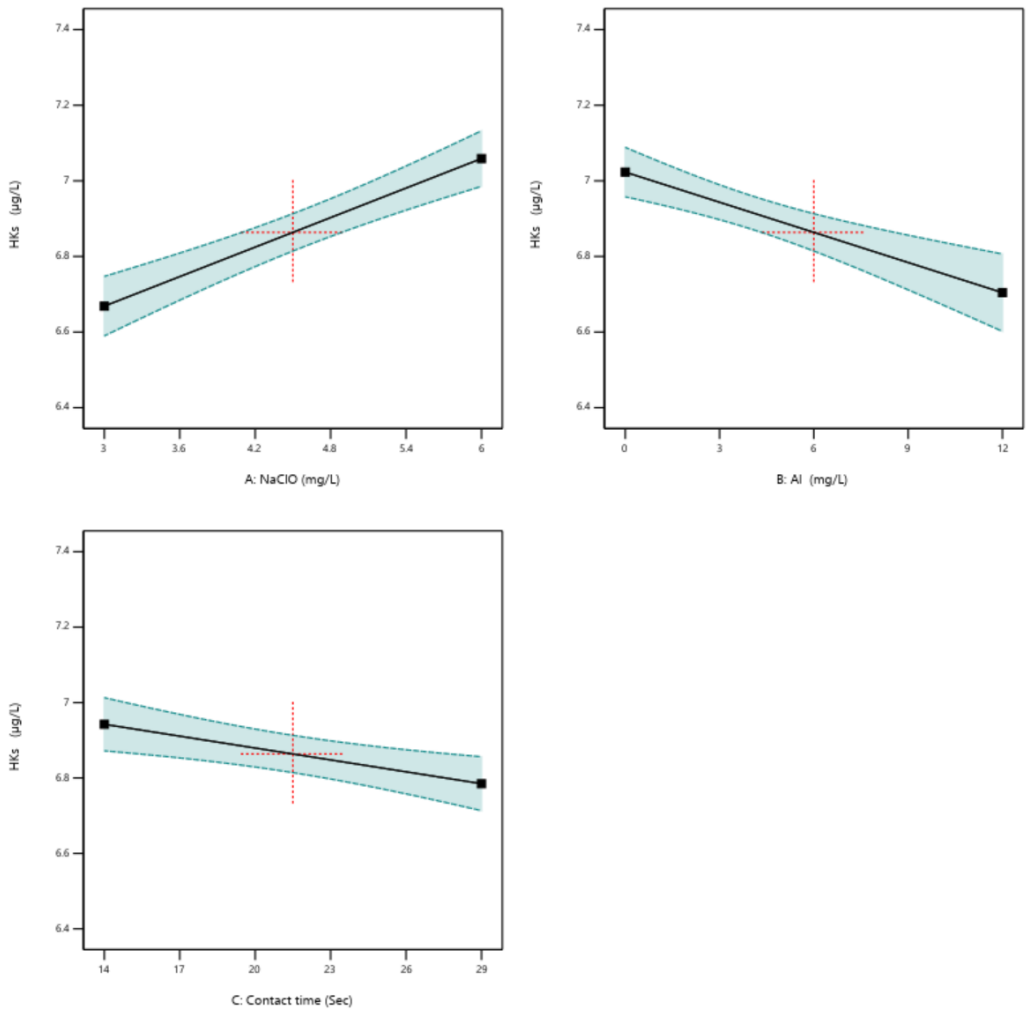

Figure S4. One-factor-at-a-time effects on HK formation; Panel A: NaClO dose, Panel B: PACl dose, Panel C: contact time.

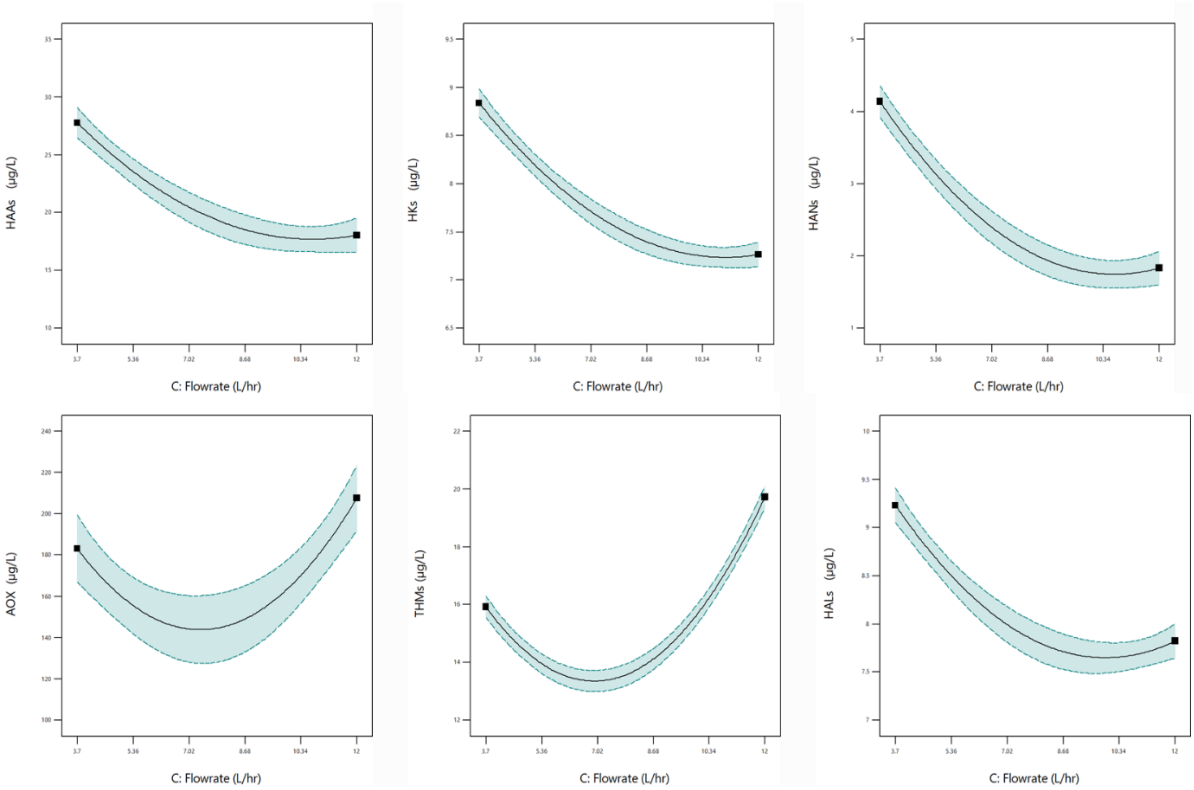

Figure S5. Profile plots of THM, HAA, AOX, HAN, HAL, and HK formation.

Table S7. ANOVA results for phosphorus removal model.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.1748	3	0.0583	27.18	< 0.0001	significant
A-NaClO	0.0017	1	0.0017	0.7702	0.3854	
B-Al	0.0651	1	0.0651	30.37	< 0.0001	
B^2	0.0384	1	0.0384	17.93	0.0001	
Residual	0.0857	40	0.0021			
Lack of Fit	0.0124	5	0.0025	1.19	0.3349	not significant
Pure Error	0.0733	35	0.0021			
Cor Total	0.2605	43				

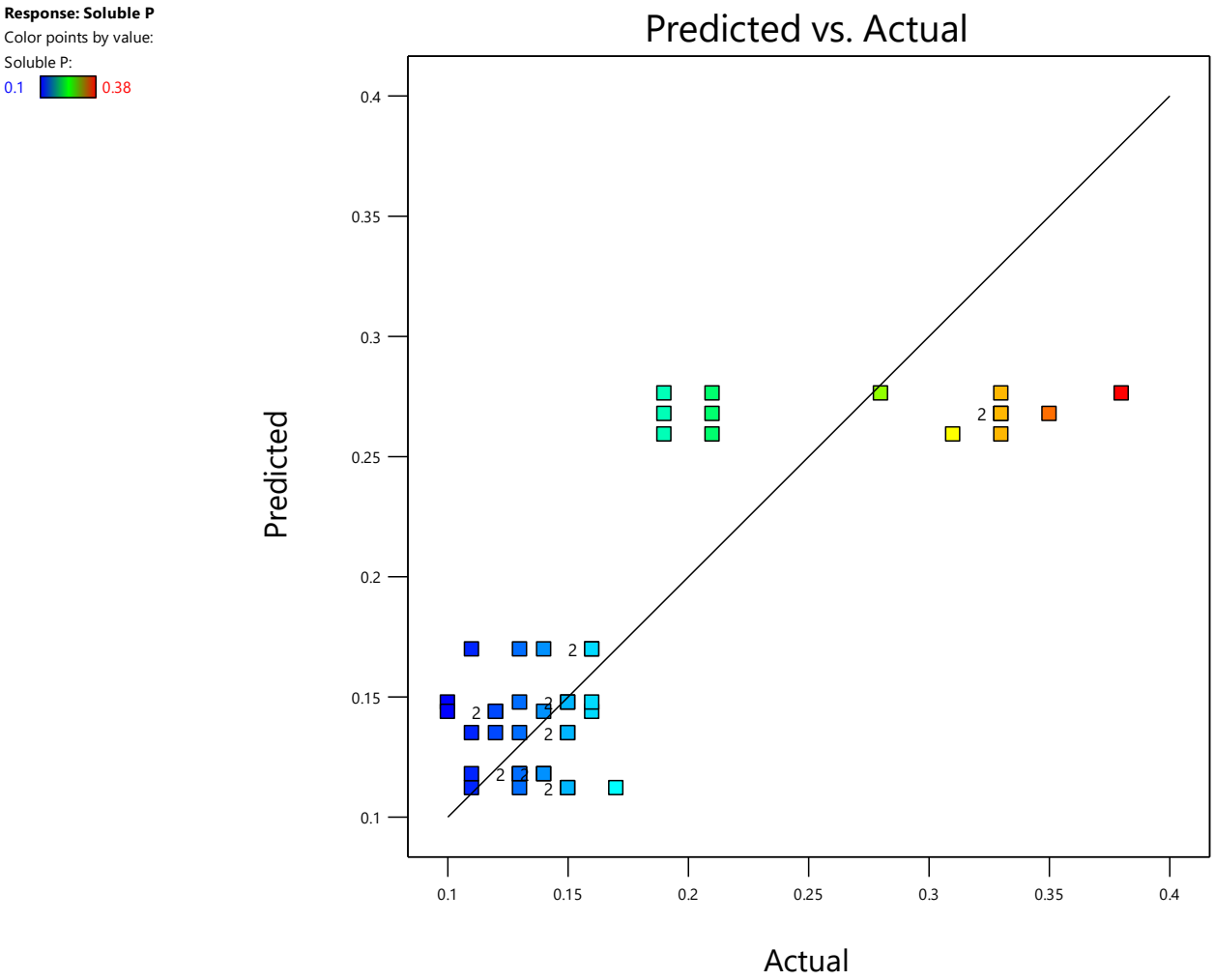

Figure S6. Actual vs. predicted values for phosphorus removal model.

Table S8. ANOVA results for Fecal Coliform inactivation model in batch system.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	4.35	1	4.35	36.18	< 0.0001	significant
A-NaClO	4.35	1	4.35	36.18	< 0.0001	
Residual	3.01	25	0.1203			
Cor Total	7.36	26				

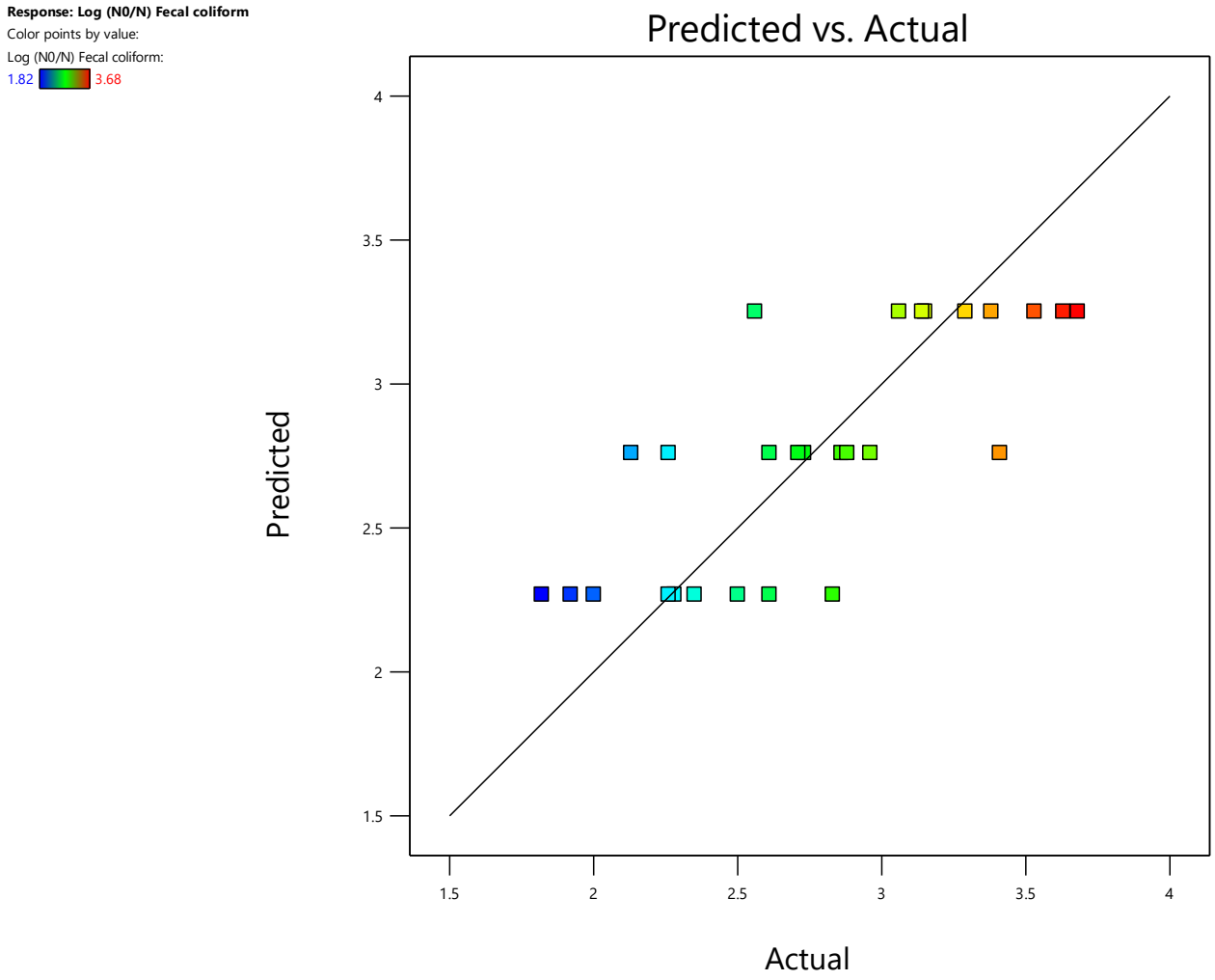

Figure S7. Actual vs. predicted values for fecal coliform inactivation model in batch system

Table S9. ANOVA results for Fecal Coliform inactivation model in pilot system.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	1.20	2	0.5984	22.43	< 0.0001	significant
A-NaClO	0.9361	1	0.9361	35.08	< 0.0001	
C-Contact time	0.1989	1	0.1989	7.45	0.0142	
Residual	0.4536	17	0.0267			
Cor Total	1.65	19				

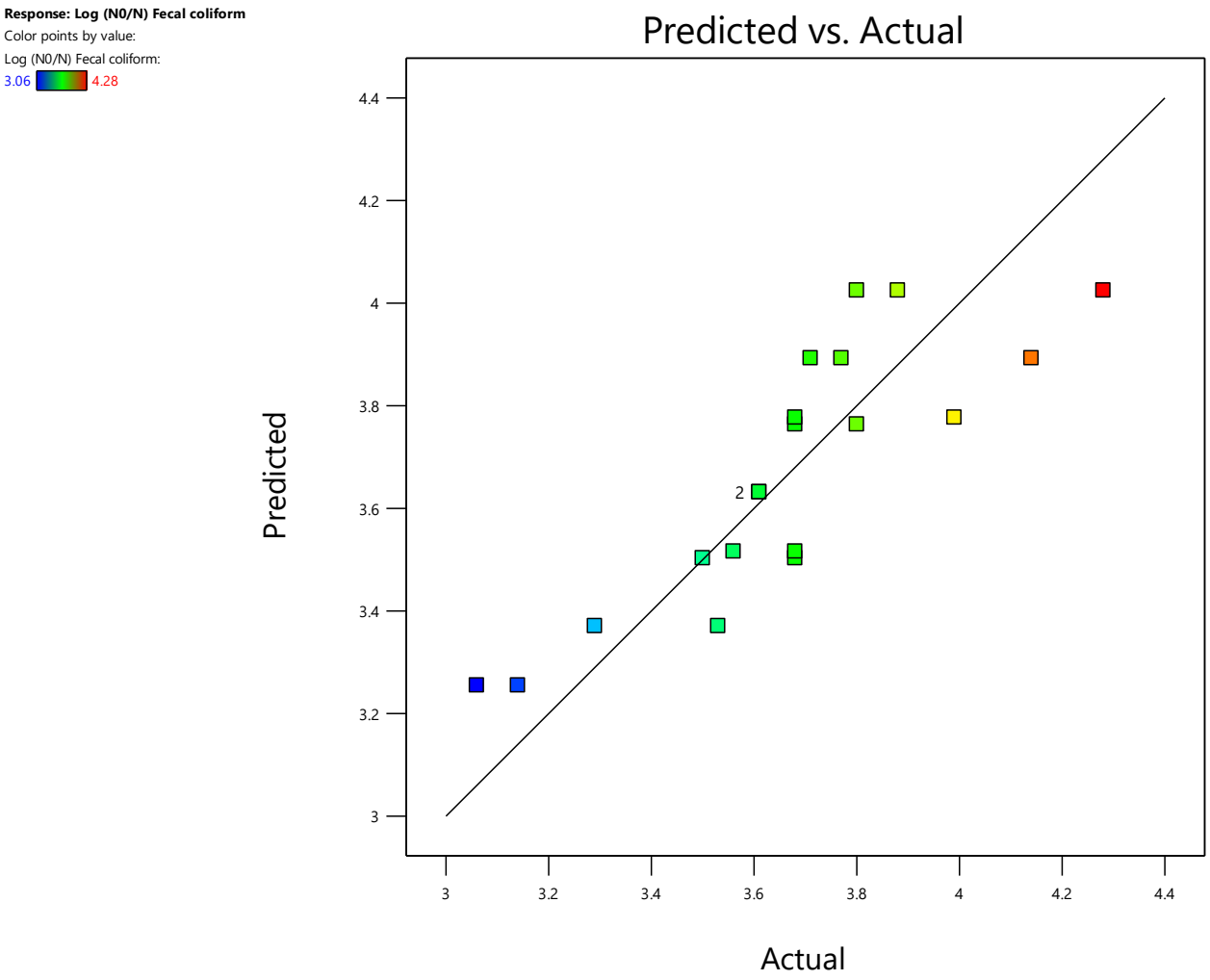

Figure S8. Actual vs. predicted values for fecal coliform inactivation model in pilot system.

Table S10. ANOVA results for Total Coliform inactivation model in batch system.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	6.76	2	3.38	50.79	< 0.0001	significant
A-NaClO	4.08	1	4.08	61.41	< 0.0001	
C-Contact time	2.23	1	2.23	33.57	< 0.0001	
Residual	1.46	22	0.0665			
Cor Total	8.22	24				

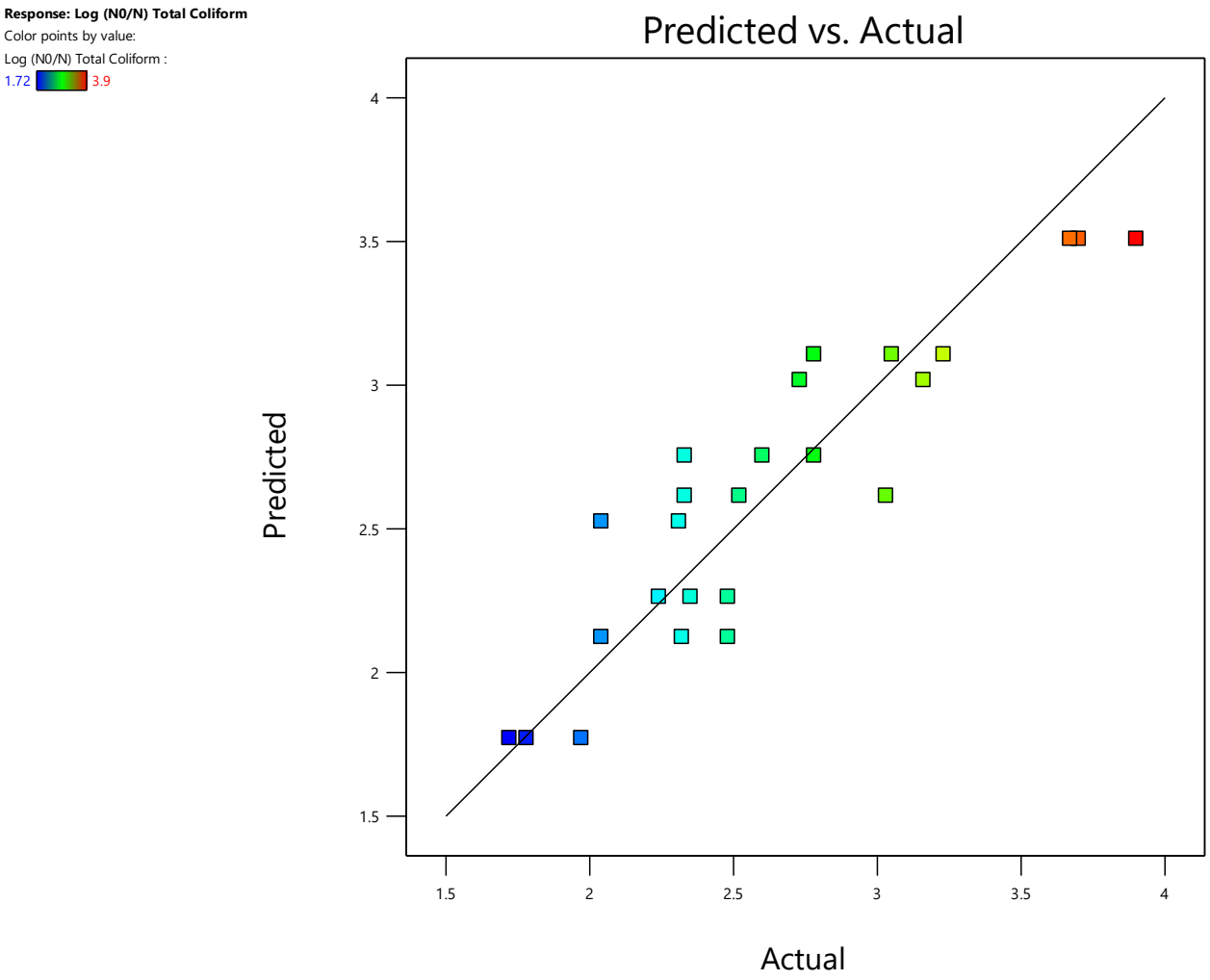

Figure S9. Actual vs. predicted values for total coliform inactivation model in batch system.

Table S11. ANOVA results for Total Coliform inactivation model in pilot system.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	1.83	2	0.9137	11.87	0.0006	significant
A-NaClO	0.8812	1	0.8812	11.45	0.0035	
C-Contact time	0.8989	1	0.8989	11.68	0.0033	
Residual	1.31	17	0.0770			
Cor Total	3.14	19				

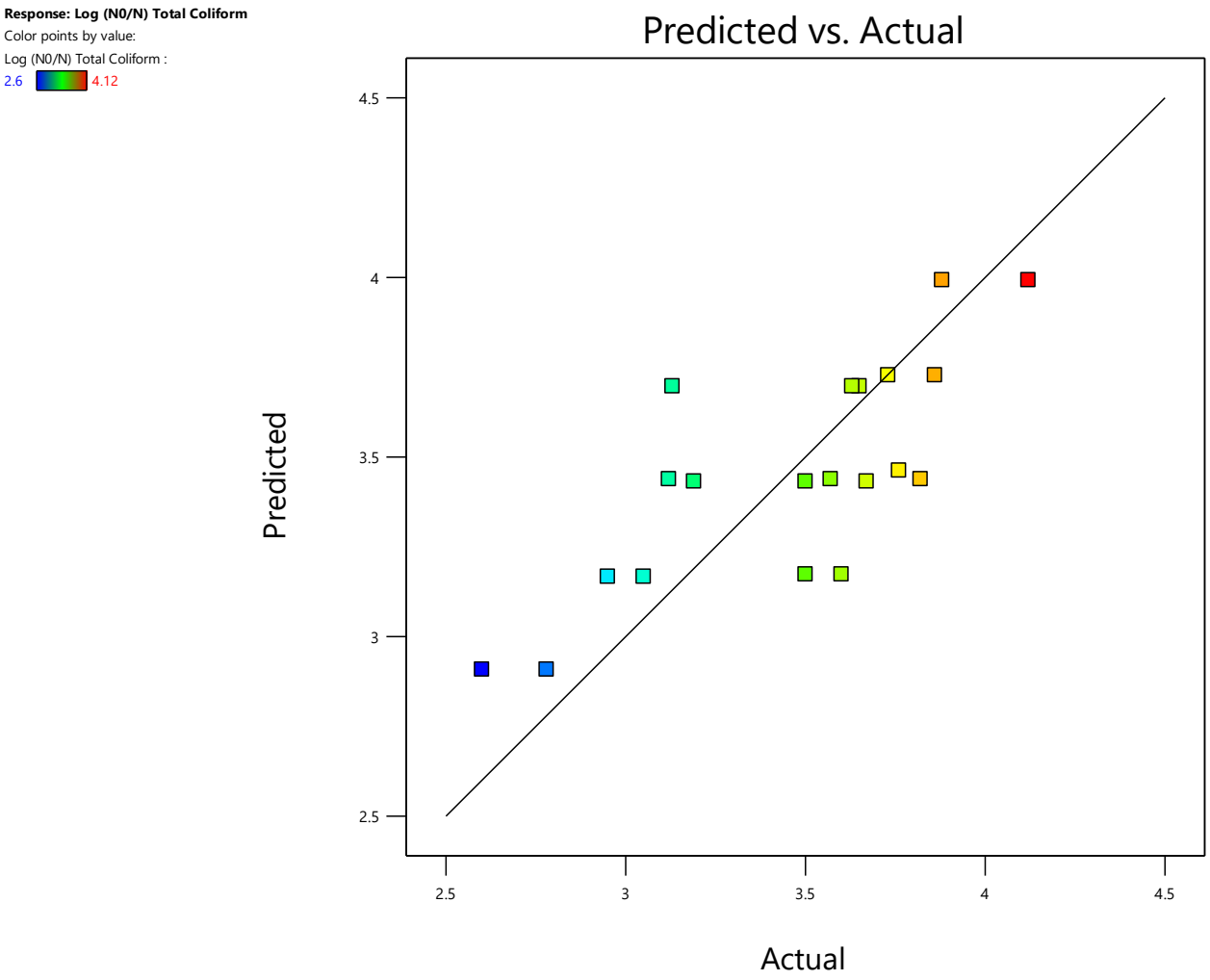

Figure S10. Actual vs. predicted values for total coliform inactivation model in pilot system

Table S12. ANOVA results for THMs formation model in batch system.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	199.13	2	99.56	6.20	0.0070	significant
C-Contact time	131.98	1	131.98	8.22	0.0087	
BC	125.60	1	125.60	7.82	0.0102	
Residual	369.34	23	16.06			
Cor Total	568.46	25				

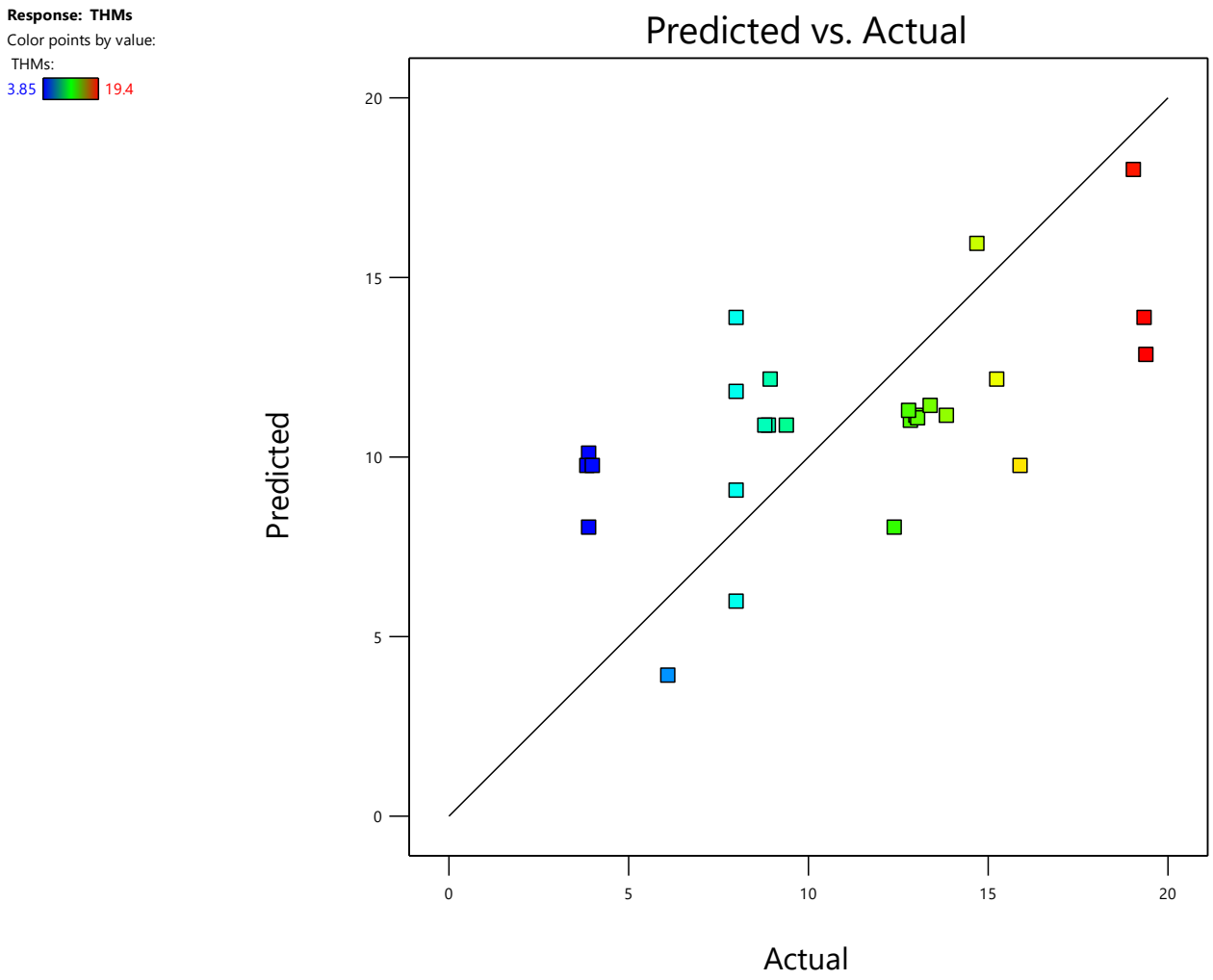

Figure S11. Actual vs. predicted values for THMs formation model in batch system

Table S13. ANOVA results for THMs formation model in pilot system.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	33.61	1	33.61	7.66	0.0122	significant
C-Contact time	33.61	1	33.61	7.66	0.0122	
Residual	83.32	19	4.39			
Cor Total	116.93	20				

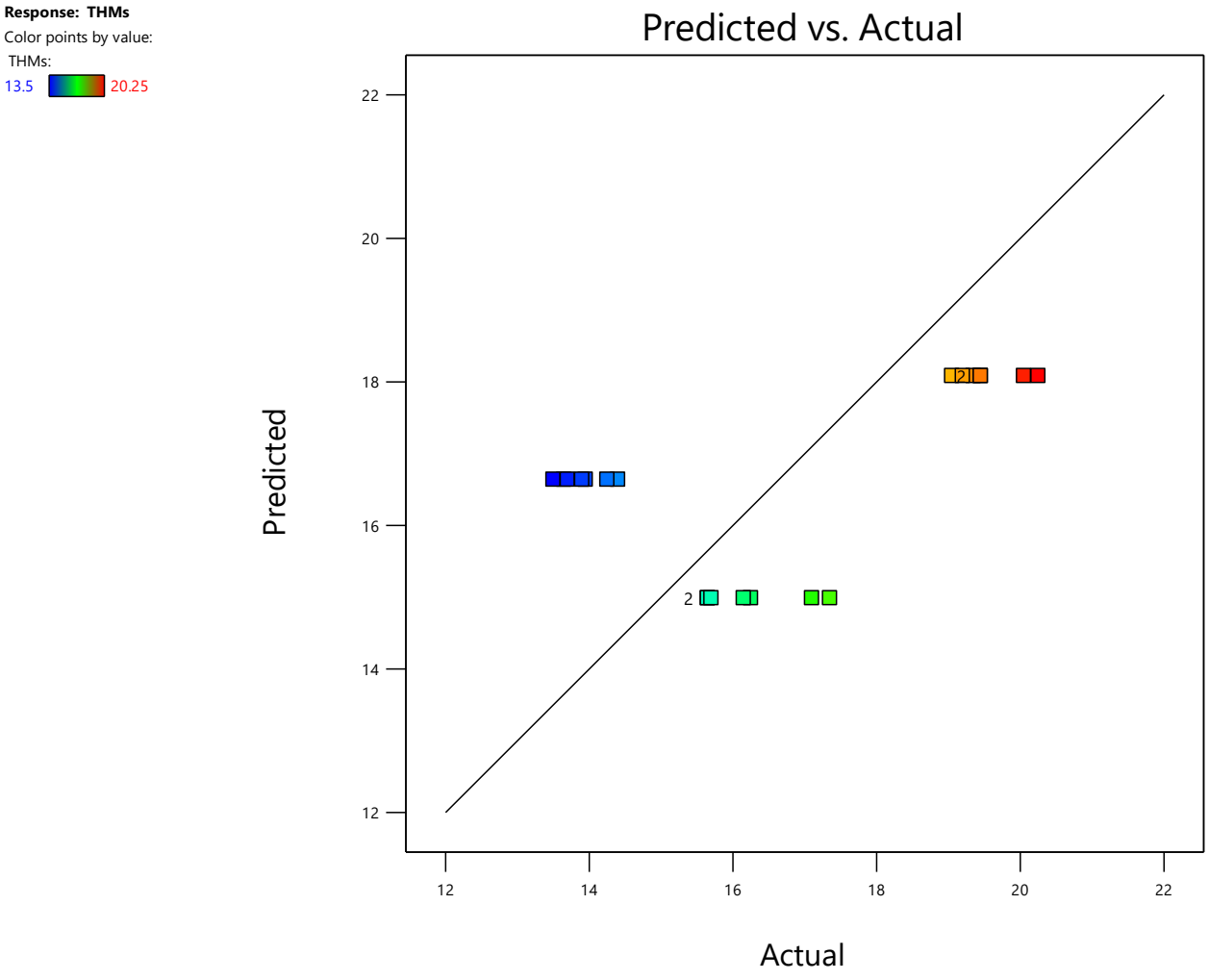

Figure S12. Actual vs. predicted values for THMs formation model in pilot system

Table S14. ANOVA results for HAAs formation model in batch system.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	74.14	3	24.71	9.31	0.0006	significant
A-NaClO	60.35	1	60.35	22.74	0.0002	
C-Contact time	2.39	1	2.39	0.8999	0.3554	
AC	18.33	1	18.33	6.91	0.0171	
Residual	47.76	18	2.65			
Cor Total	121.90	21				

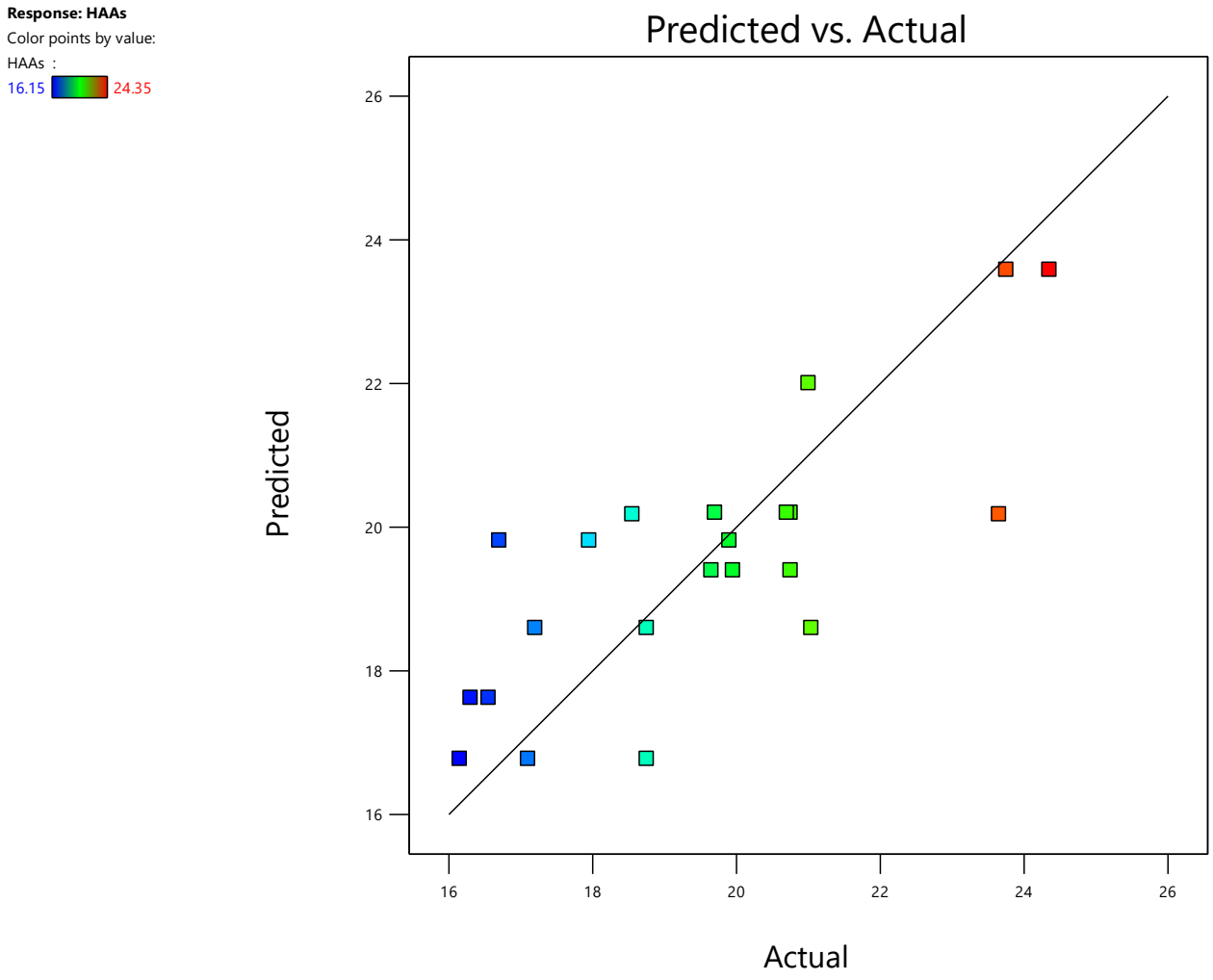

Figure S13. Actual vs. predicted values for HAAs formation model in batch system

Table S15. ANOVA results for HAAs formation model in pilot system.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	347.41	3	115.80	12.81	< 0.0001	significant
A-NaClO	10.54	1	10.54	1.17	0.2930	
C-Contact time	270.54	1	270.54	29.93	< 0.0001	
AC	28.96	1	28.96	3.20	0.0886	
Residual	180.76	20	9.04			
Cor Total	528.17	23				

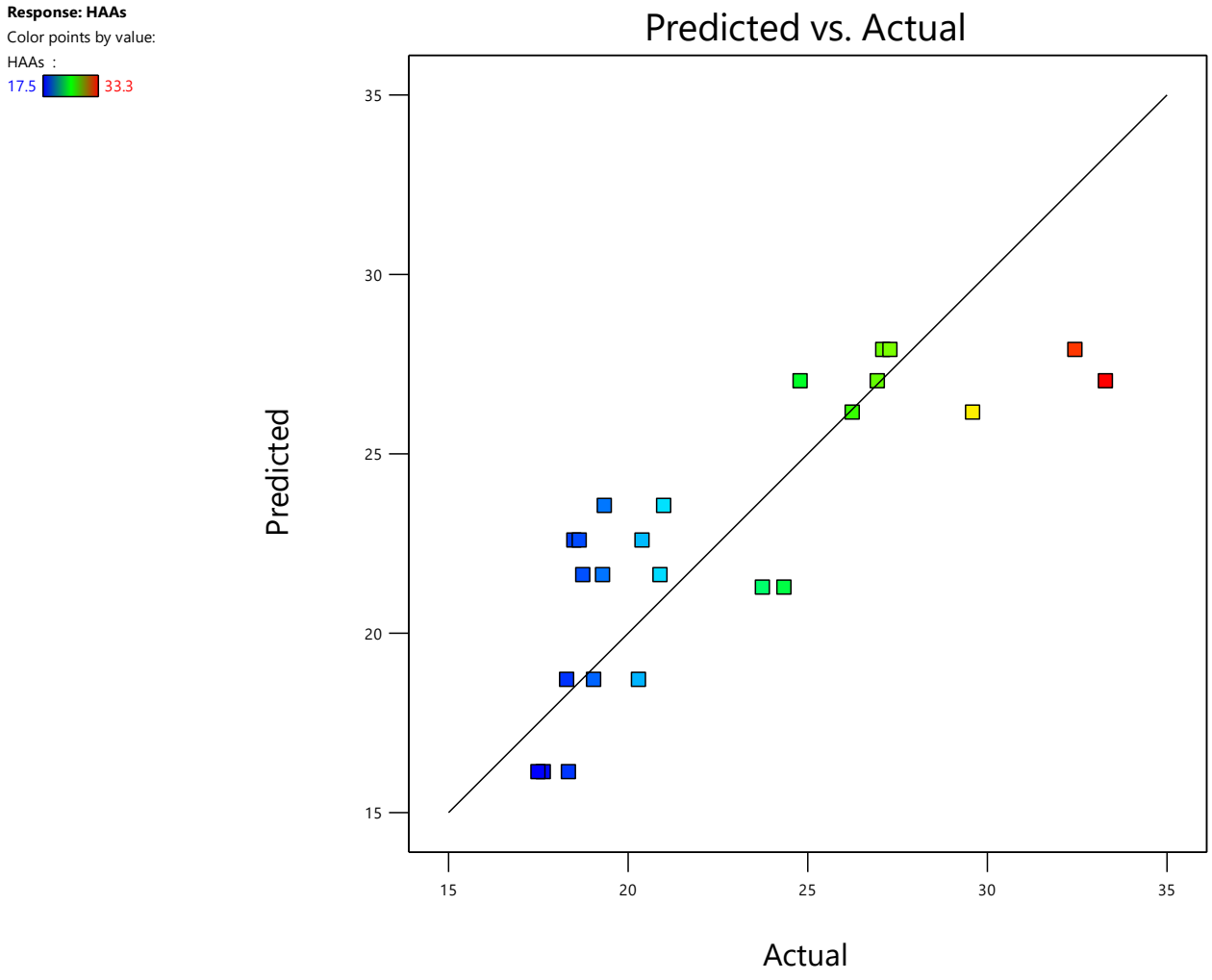

Figure S14. Actual vs. predicted values for HAAs formation model in pilot system.

Table S16. ANOVA results for HALs formation model in batch system.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.5004	4	0.1251	6.08	0.0036	significant
A-NaClO	0.0913	1	0.0913	4.44	0.0513	
B-Al	0.1121	1	0.1121	5.45	0.0330	
C-Contact time	0.0103	1	0.0103	0.5012	0.4891	
AC	0.2009	1	0.2009	9.77	0.0065	
Residual	0.3291	16	0.0206			
Cor Total	0.8295	20				

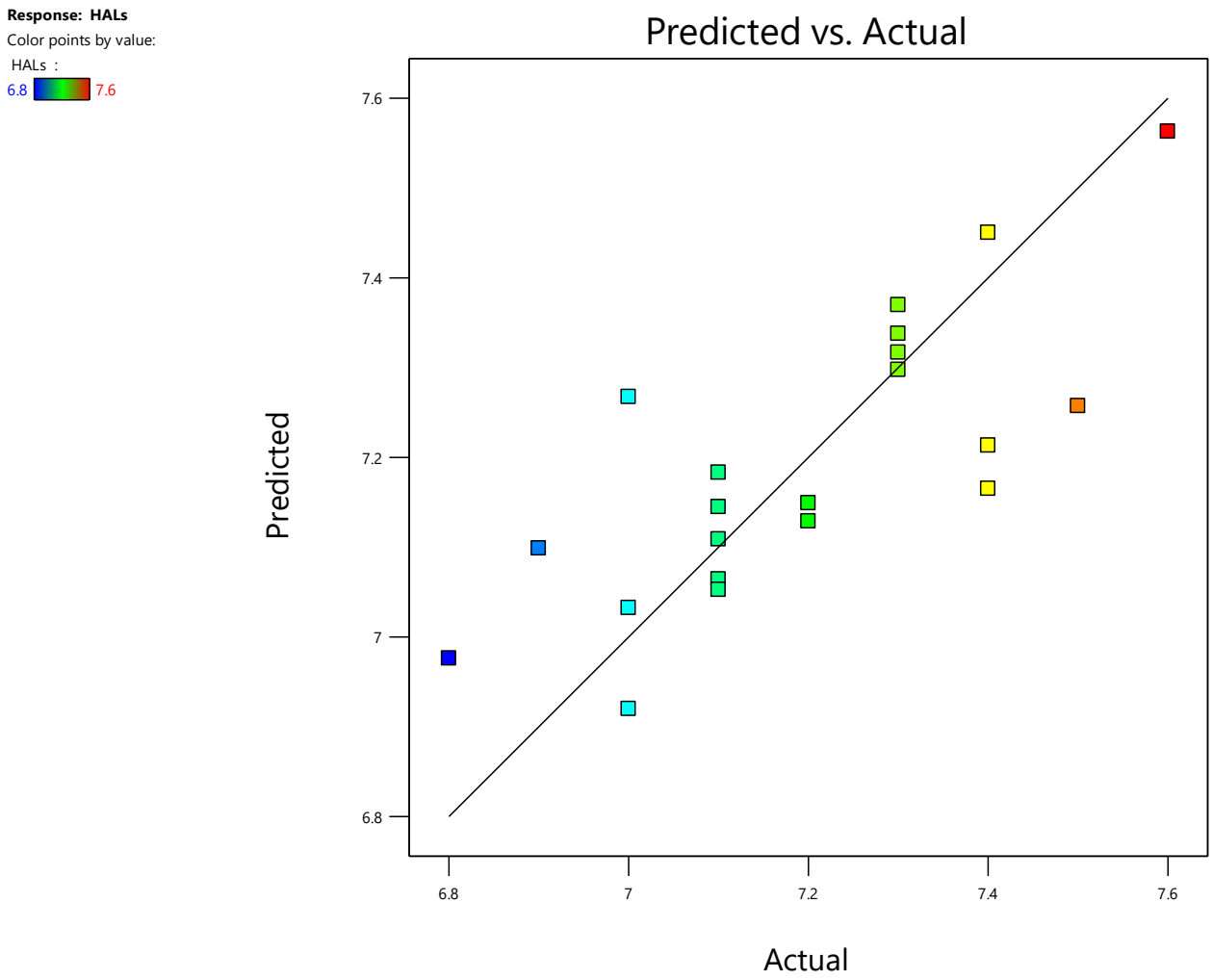

Figure S15. Actual vs. predicted values for HALs formation model in batch system

Table S17. ANOVA results for HALs formation model in pilot system.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	11.29	1	11.29	54.14	< 0.0001	significant
C-Contact time	11.29	1	11.29	54.14	< 0.0001	
Residual	4.38	21	0.2086			
Cor Total	15.67	22				

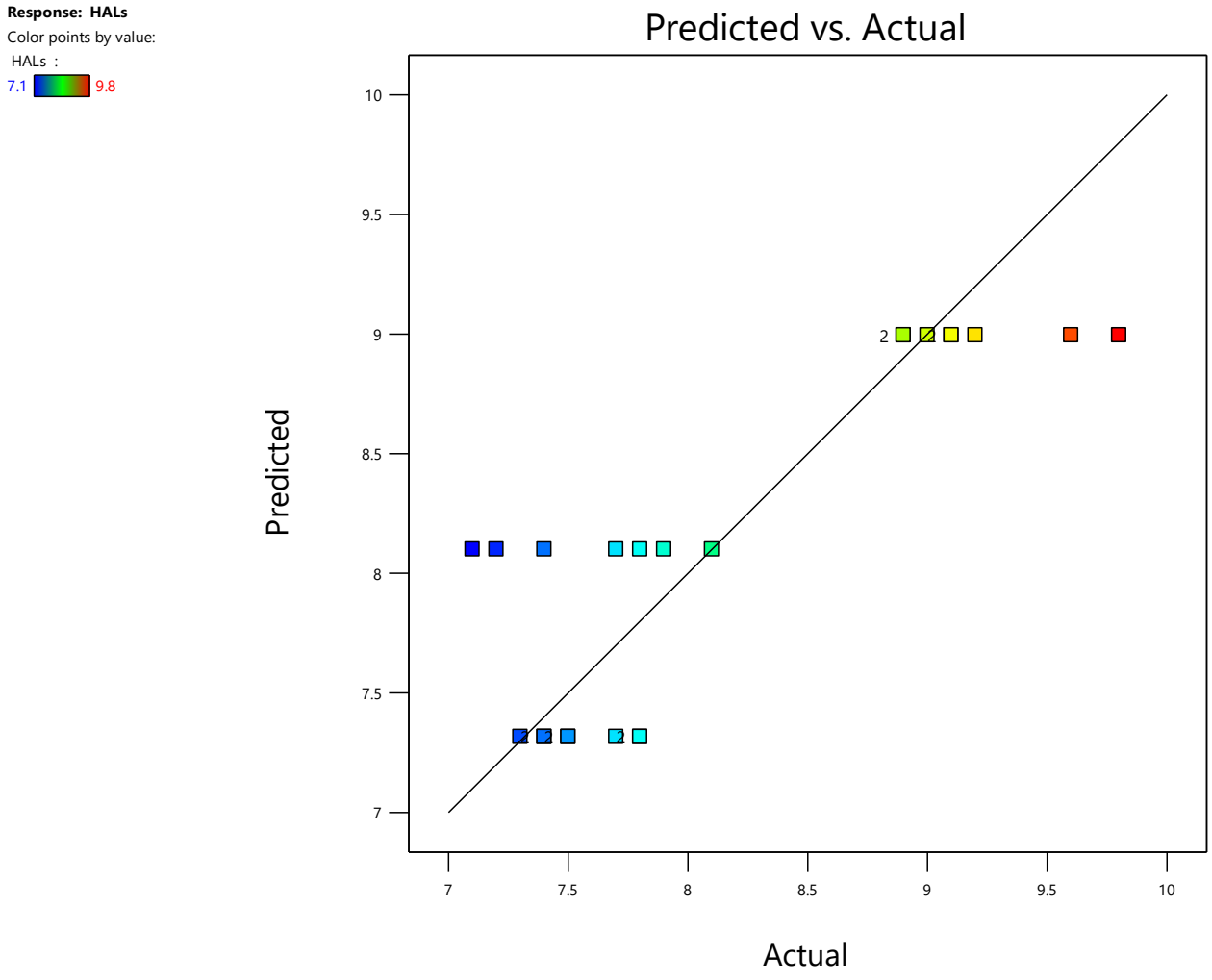

Figure S16. Actual vs. predicted values for HALs formation model in pilot system

Table S18. ANOVA results for HKs formation model in batch system.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.7431	3	0.2477	23.01	< 0.0001	significant
A-NaClO	0.5318	1	0.5318	49.41	< 0.0001	
B-Al	0.2416	1	0.2416	22.45	0.0001	
C-Contact time	0.1118	1	0.1118	10.38	0.0043	
Residual	0.2153	20	0.0108			
Cor Total	0.9583	23				

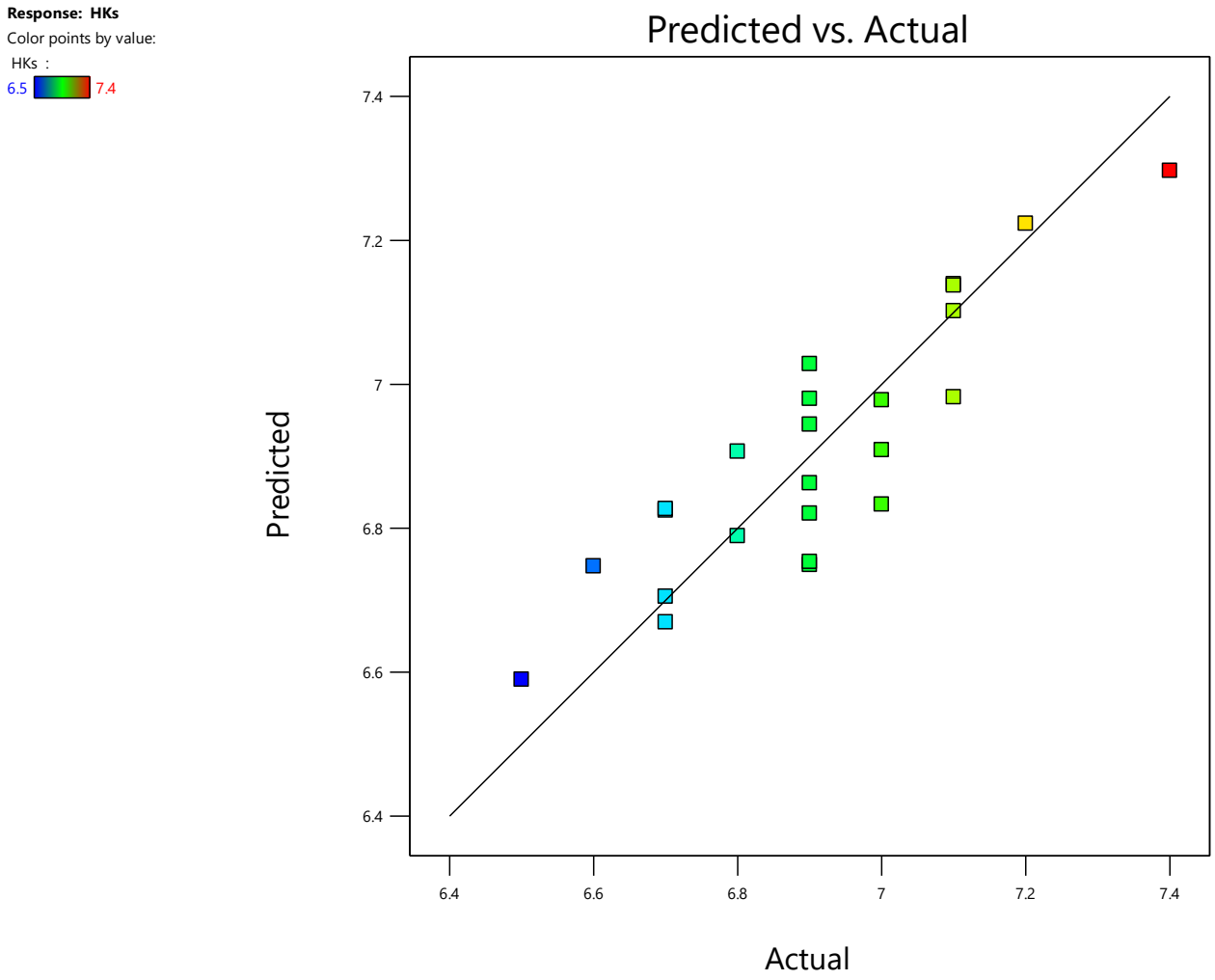

Figure S17. Actual vs. predicted values for HKs formation model in batch system

Table S19. ANOVA results for HKs formation model in pilot system.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	9.09	6	1.52	165.97	< 0.0001	significant
A-NaClO	0.0924	1	0.0924	10.13	0.0067	
B-Al	0.2514	1	0.2514	27.54	0.0001	
C-Contact time	7.90	1	7.90	865.67	< 0.0001	
BC	0.1145	1	0.1145	12.54	0.0033	
A^2	0.0947	1	0.0947	10.37	0.0062	
C^2	0.9092	1	0.9092	99.60	< 0.0001	
Residual	0.1278	14	0.0091			
Cor Total	9.22	20				
Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	9.09	6	1.52	165.97	< 0.0001	significant

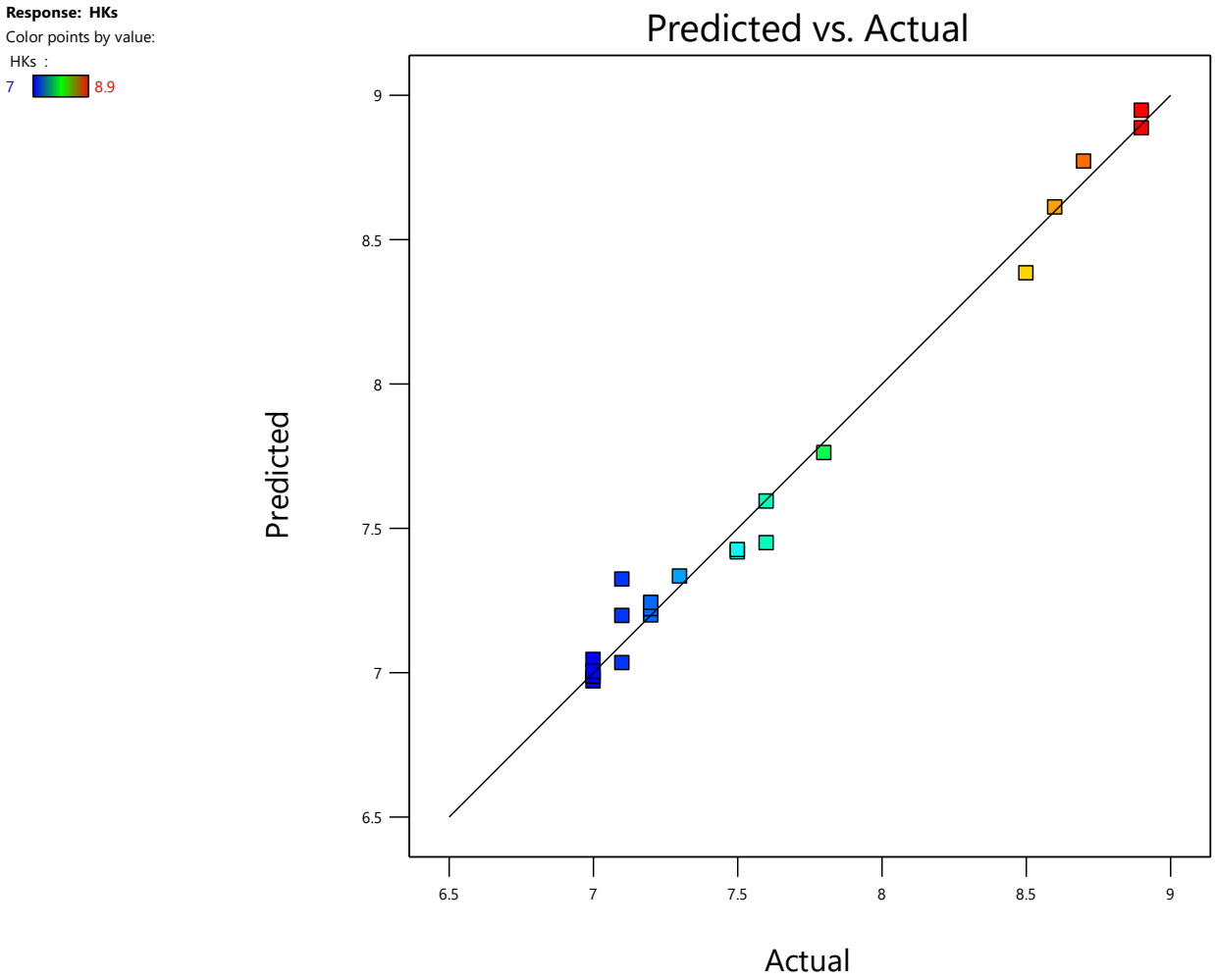

Figure S18. Actual vs. predicted values for HKs formation model in pilot system