

APPENDIX A

Table A1: Data for removal efficiency with time using NaClO in bubble column (initial SO₂ concentration 6348 ppm, initial NO concentration 1804 ppm, initial pH 5.6, initial NaClO concentration 0.032 M, temperature 305 K)

| S. No. | Time (min) | NO removal efficiency (%) | SO ₂ removal efficiency (%) |
|--------|------------|---------------------------|--|
| 1 | 0 | 0 | 0 |
| 2 | 5 | 45.83 | 97.12 |
| 3 | 10 | 62.34 | 97.23 |
| 4 | 15 | 76.18 | 97.32 |
| 5 | 20 | 84.52 | 97.24 |
| 6 | 25 | 85.15 | 97.28 |
| 7 | 30 | 86.25 | 97.52 |
| 8 | 35 | 91.25 | 98.25 |
| 9 | 40 | 91.23 | 98.35 |
| 10 | 50 | 89.25 | 98.25 |
| 11 | 60 | 90.13 | 98.12 |
| 12 | 70 | 90.12 | 98.56 |
| 13 | 80 | 89.25 | 97.54 |
| 14 | 90 | 89.56 | 97.64 |

| | | | |
|-----------|-----|-------|-------|
| 15 | 100 | 89.23 | 98.14 |
| 16 | 110 | 88.25 | 97.42 |
| 17 | 120 | 89.68 | 98.25 |
| 18 | 130 | 85.25 | 96.13 |
| 19 | 140 | 82.12 | 92.13 |
| 20 | 150 | 78.32 | 89.12 |
| 21 | 160 | 72.13 | 78.12 |
| 22 | 170 | 65.12 | 74.97 |
| 23 | 180 | 61.13 | 68.12 |
| 24 | 190 | 58.23 | 65.12 |
| 25 | 200 | 53.25 | 56.12 |
| 26 | 210 | 40.12 | 50.35 |
| 27 | 220 | 35.12 | 48.23 |
| 28 | 220 | 23.45 | 45.28 |
| 29 | 230 | 18.25 | 33.89 |
| 30 | 240 | 11.23 | 29.56 |
| 31 | 250 | 6.12 | 23.28 |
| 32 | 260 | 0 | 19.63 |
| 33 | 270 | 0 | 18.23 |
| 34 | 280 | 0 | 15.23 |
| 35 | 290 | 0 | 12.36 |

| | | | |
|-----------|-----|---|------|
| 36 | 300 | 0 | 8.25 |
| 37 | 310 | 0 | 4.67 |
| 38 | 320 | 0 | 2.63 |
| 39 | 330 | 0 | 1.13 |
| 40 | 340 | 0 | 0.89 |
| 41 | 350 | 0 | 0 |

Table A2: Data for removal efficiency with NaClO concentration in bubble column (initial SO₂ concentration 6348 ppm, initial NO concentration 1804 ppm, temperature 305 K, initial pH 5.6)

| S. No. | NaClO concentration (M) | NO removal efficiency (%) | SO₂ removal efficiency (%) |
|---------------|--------------------------------|----------------------------------|--|
| 1 | 0.004 | 82.73 | 96.14 |
| 2 | 0.008 | 83.71 | 97.12 |
| 3 | 0.012 | 85.97 | 97.15 |
| 4 | 0.016 | 86.71 | 98.12 |
| 5 | 0.02 | 87.97 | 98.25 |
| 6 | 0.024 | 89.71 | 98.12 |

| | | | |
|-----------|-------|-------|-------|
| 7 | 0.028 | 90.55 | 98.05 |
| 8 | 0.032 | 90.97 | 98.35 |
| 9 | 0.036 | 90.97 | 98.15 |
| 10 | 0.04 | 90.97 | 98.62 |

Table A3: Data for removal efficiency with absorbent temperature using NaClO in stirred vessel (initial SO₂ concentration 6348 ppm, initial NO concentration 1804 ppm, initial pH 5.6, initial NaClO concentration 0.032 M)

| S. No. | Temperature (K) | NO removal efficiency (%) | SO₂ removal efficiency (%) |
|---------------|------------------------|----------------------------------|--|
| 1 | 283 | 82.291234 | 97.9823 |
| 2 | 294 | 86.91452097 | 97.58174905 |
| 3 | 305 | 91.9690926 | 97.84790875 |
| 4 | 315 | 87.56278214 | 97.80988593 |
| 5 | 324 | 87.41190006 | 97.88593156 |

Table A4: Data for removal efficiency with time using NaClO in stirred vessel (initial SO₂ concentration 6340 ppm, initial NO concentration 816 ppm, initial NaClO concentration 0.01 M, temperature 313 K)

| S. No. | Time (min) | NO removal efficiency (%) | SO ₂ removal efficiency (%) |
|--------|---------------|---------------------------|--|
| 1 | 0 | 0.00 | 0.00 |
| 2 | 20 | 99.81 | 92.56 |
| 3 | 40 | 99.58 | 89.66 |
| 4 | 60 | 98.97 | 85.81 |
| 5 | 80 | 98.52 | 80.36 |
| 6 | 100 | 98.10 | 75.84 |
| 7 | 120 | 97.38 | 71.45 |

Table A5: Data for removal efficiency with NaClO concentration in stirred vessel (initial SO₂ Concentration 6340 ppm, initial NO Concentration 816 ppm, temperature 313 K)

| S. No. | NaClO concentration (M) | NO removal efficiency (%) | SO₂ removal efficiency (%) |
|---------------|--------------------------------|----------------------------------|--|
| 1 | 0.002 | 84.73 | 97.34 |
| 2 | 0.005 | 88.71 | 99.32 |
| 3 | 0.008 | 91.85 | 99.64 |
| 4 | 0.010 | 92.56 | 99.85 |
| 5 | 0.012 | 92.58 | 99.81 |

Table A6: Data for removal efficiency with absorbent temperature using NaClO in stirred vessel (initial SO₂ concentration 6340 ppm, initial NO concentration 816 ppm, initial NaClO concentration 0.01 M)

| S. No. | Temperature (K) | NO removal efficiency (%) | SO ₂ removal efficiency (%) |
|--------|-----------------|---------------------------|--|
| 1 | 293 | 87.91 | 99.58 |
| 2 | 303 | 90.97 | 99.85 |
| 3 | 313 | 92.56 | 99.81 |
| 4 | 323 | 91.10 | 99.89 |

Table A7: Data for removal efficiency with initial SO₂ concentration using NaClO in stirred vessel (initial NO concentration 816 ppm, initial NaClO concentration 0.01 M, temperature 313 K)

| S. No. | SO ₂ concentration (ppm) | NO removal efficiency (%) | SO ₂ removal efficiency (%) |
|--------|--|------------------------------|---|
| 1 | 4171 | 84.78 | 99.71 |
| 2 | 5124 | 87.51 | 99.77 |
| 3 | 6340 | 92.56 | 99.81 |
| 4 | 7136 | 93.26 | 99.83 |

Table A8: Data for removal efficiency with initial NO concentration using NaClO in stirred vessel (initial SO₂ concentration 6340 ppm, initial NaClO concentration 0.01 M, temperature 313 K)

| S. No. | NO concentration (ppm) | NO removal efficiency (%) | SO₂ removal efficiency (%) |
|---------------|-----------------------------------|--------------------------------------|--|
| 1 | 508 | 87.10 | 99.71 |
| 2 | 614 | 89.12 | 99.77 |
| 3 | 721 | 91.28 | 99.81 |
| 4 | 817 | 92.56 | 99.83 |

Table A9: Data for removal efficiency with initial pH of NaClO in stirred vessel (initial SO₂ concentration 6340 ppm, initial NO concentration 816 ppm, initial NaClO concentration 0.01 M, temperature 313 K)

| S. No. | Initial pH | NO removal efficiency (%) | SO ₂ removal efficiency (%) |
|--------|------------|---------------------------|--|
| 1 | 4 | 88.14 | 99.58 |
| 2 | 5 | 91.27 | 99.78 |
| 3 | 5.8 | 92.12 | 99.85 |
| 4 | 6.8 | 86.67 | 99.81 |
| 5 | 7.6 | 77.45 | 99.82 |
| 6 | 9 | 54.23 | 99.27 |

Table A10: Data for removal efficiency with $\text{Ca}(\text{OCl})_2$ concentration in stirred vessel (initial SO_2 concentration 6126 ppm, initial NO concentration 876 ppm, temperature 313 K)

| S. No. | $\text{Ca}(\text{OCl})_2$ concentration (g/100ml) | NO removal efficiency (%) | SO_2 removal efficiency (%) |
|---------------|---|----------------------------------|--|
| 1 | 1 | 74.73 | 97.34 |
| 2 | 2 | 78.71 | 99.32 |
| 3 | 4 | 80.97 | 99.85 |
| 4 | 5 | 84.47 | 99.89 |
| 5 | 6 | 84.68 | 99.91 |
| 6 | 7 | 84.97 | 99.95 |

Table A11: Data for removal efficiency with absorbent temperature using $\text{Ca}(\text{OCl})_2$ in stirred vessel (initial SO_2 concentration 6126 ppm, initial NO concentration 876 ppm, absorbent concentration 5 g/100ml)

| S. No. | Temperature (K) | NO removal efficiency (%) | SO₂ removal efficiency (%) |
|---------------|------------------------|----------------------------------|--|
| 1 | 293 | 84.91 | 99.58 |
| 2 | 303 | 87.97 | 99.85 |
| 3 | 313 | 89.56 | 99.81 |
| 4 | 323 | 90.10 | 99.89 |

Table A12: Data for removal efficiency with mole ratio of absorbent blend NaOH/NaClO in magnetic stirred vessel (initial SO₂ concentration 6829 ppm, initial NO concentration 850 ppm, temperature 313 K, initial pH 5.9, NaClO concentration 0.024 M)

| S. No. | Mole ratio of NaClO/NaOH | NO removal efficiency (%) | SO₂ removal efficiency (%) |
|---------------|---------------------------------|----------------------------------|--|
| 1 | 0.5 | 80.73 | 98.14 |
| 2 | 1 | 81.71 | 98.12 |
| 3 | 1.5 | 82.97 | 98.15 |
| 4 | 2 | 83.71 | 98.12 |
| 5 | 2.5 | 85.97 | 98.25 |
| 6 | 3 | 87.71 | 98.12 |
| 7 | 3.5 | 87.97 | 98.35 |
| 8 | 4 | 87.96 | 98.35 |

Table A13: Data for removal efficiency with absorbent temperature in magnetic stirrer vessel using NaOH/NaClO blend (initial SO₂ concentration 6829 ppm, initial NO concentration 850 ppm, initial pH 5.9, mole ratio of NaOH/NaClO 3)

| S. No. | Temperature (K) | NO removal efficiency (%) | SO ₂ removal efficiency (%) |
|--------|-----------------|---------------------------|--|
| 1 | 293 | 81.91 | 97.58 |
| 2 | 303 | 84.97 | 97.85 |
| 3 | 313 | 87.56 | 97.81 |
| 4 | 323 | 87.41 | 97.89 |

Table A14: Data for estimation of k_{SO_2g} with NaClO

| S. No. | Absorption rate ($\times 10^{-6}$ mole/m ² ·s) | Partial pressure of SO ₂ ($\times 10^{10}$.Pa) |
|--------|--|---|
| 1 | 1.67 | 2.37 |
| 2 | 2.06 | 2.92 |
| 3 | 2.54 | 3.61 |
| 4 | 2.86 | 4.06 |

Table A15: Data for estimation of reaction order for NO with NaClO

| S. No. | $-\log (C_{\text{NOi}})$ | $\log (N_{\text{NO}})$ |
|--------|--------------------------|------------------------|
| 1 | 9.92 | 12.13 |
| 2 | 9.72 | 11.92 |
| 3 | 9.56 | 11.73 |
| 4 | 9.44 | 11.60 |

Table A16: Data for enthalpy change with temperature using NaClO

| S. No. | Temperature (K) | ΔH (kJ·mol ⁻¹) |
|--------|-----------------|------------------------------------|
| 1 | 283 | 3171.63 |
| 2 | 293 | 3178.24 |
| 3 | 303 | 3184.84 |
| 4 | 313 | 3191.45 |
| 5 | 323 | 3198.05 |
| 6 | 333 | 3204.65 |
| 7 | 343 | 3211.26 |
| 8 | 353 | 3217.86 |

Table A17: Data for Gibbs free energy change with temperature using NaClO

| S. No. | Temperature (K) | ΔG (kJ·mol⁻¹) |
|---------------|------------------------|--|
| 1 | 303 | 2932.05 |
| 2 | 313 | 2703.36 |
| 3 | 323 | 2585.47 |
| 4 | 333 | 2499.16 |
| 5 | 343 | 2427.68 |
| 6 | 353 | 2364.69 |

Table A18: Data for removal efficiency with time using NaClO in spray column (gas flow rate 600 mL/min, liquid flow rate 1500 mL/min, initial NaClO concentration 0.024 M, distributor diameter 1 mm, temperature 313 K)

| S. No. | Time (min) | NO removal efficiency (%) | SO ₂ removal efficiency (%) |
|--------|------------|---------------------------|--|
| 1 | 0 | 0.00 | 0.00 |
| 2 | 20 | 82.56 | 97.81 |
| 3 | 40 | 75.66 | 97.58 |
| 4 | 60 | 71.81 | 96.97 |
| 5 | 80 | 66.36 | 96.52 |
| 6 | 100 | 63.84 | 96.10 |
| 7 | 120 | 57.45 | 95.38 |
| 8 | 140 | 51.81 | 90.97 |
| 9 | 160 | 46.36 | 86.52 |
| 10 | 180 | 38.84 | 81.10 |
| 11 | 200 | 31.45 | 75.38 |

Table A19: Data for removal efficiency with absorbent (NaClO) concentration in spray column (gas flow rate 600 mL/min, liquid flow rate 1500 mL/min, temperature 313 K, distributor diameter 1 mm, time 120 min)

| S. No. | NaClO concentration (M) | NO removal efficiency (%) | SO₂ removal efficiency (%) |
|---------------|--------------------------------|----------------------------------|--|
| 1 | 0.004 | 64.73 | 91.34 |
| 2 | 0.008 | 68.71 | 93.32 |
| 3 | 0.012 | 70.97 | 95.85 |
| 4 | 0.016 | 74.71 | 97.32 |
| 5 | 0.02 | 78.97 | 97.85 |
| 6 | 0.024 | 79.71 | 98.32 |
| 7 | 0.028 | 81.97 | 98.85 |
| 8 | 0.032 | 82.56 | 98.85 |

Table A20: Data for removal efficiency with reaction temperature using NaClO in spray column (gas flow rate 600 mL/min, liquid flow rate 1500 mL/min, initial NaClO concentration 0.024 M, distributor diameter 1 mm, time 120 min)

| S. No. | Temperature (K) | NO removal efficiency (%) | SO₂ removal efficiency (%) |
|---------------|------------------------|----------------------------------|--|
| 1 | 293 | 77.91 | 97.58 |
| 2 | 303 | 80.97 | 97.85 |
| 3 | 313 | 82.56 | 97.81 |
| 4 | 323 | 81.10 | 97.89 |

Table A21: Data for removal efficiency with initial SO₂ concentration using NaClO in spray column (gas flow rate 600 mL/min, liquid flow rate 1500 mL/min, initial NaClO concentration 0.024 M, distributor diameter 1 mm, temperature 313 K, time 120 min)

| S. No. | SO ₂ concentration (ppm) | NO removal efficiency (%) | SO ₂ removal efficiency (%) |
|--------|--|------------------------------|---|
| 1 | 2432 | 81.56 | 97.81 |
| 2 | 3528 | 81.66 | 97.58 |
| 3 | 4635 | 82.81 | 96.97 |
| 4 | 5712 | 86.36 | 96.52 |
| 5 | 6817 | 87.84 | 96.10 |

Table A22: Data for removal efficiency with initial NO concentration using NaClO in spray column (gas flow rate 600 mL/min, liquid flow rate 1500 mL/min, initial NaClO concentration 0.024 M, distributor diameter 1 mm, temperature 313 K, time 120 min)

| S. No. | NO concentration (ppm) | NO removal efficiency (%) | SO₂ removal efficiency (%) |
|---------------|-------------------------------|----------------------------------|--|
| 1 | 432 | 80.56 | 97.81 |
| 2 | 528 | 81.66 | 97.58 |
| 3 | 635 | 84.81 | 96.97 |
| 4 | 712 | 86.36 | 96.52 |
| 5 | 817 | 87.84 | 96.10 |

Table A23: Data for removal efficiency with initial pH of absorbent using NaClO in spray column (gas flow rate 600 mL/min, liquid flow rate 1500 mL/min, initial NaClO concentration 0.024 M, distributor diameter 1 mm, temperature 313 K, time 120 min)

| S. No. | Initial pH | NO removal efficiency (%) | SO ₂ removal efficiency (%) |
|--------|------------|---------------------------|--|
| 1 | 4.1 | 82.56 | 97.81 |
| 2 | 4.9 | 84.66 | 97.58 |
| 3 | 5.4 | 85.81 | 96.97 |
| 4 | 6.7 | 76.36 | 96.52 |
| 5 | 7.8 | 63.84 | 96.10 |
| 6 | 9.2 | 51.45 | 95.38 |

Table A24: Data for removal efficiency with addition of CO₂ to simulated gas stream using NaClO in spray column (initial NO concentration 600 ppm, initial SO₂ concentration 2600 ppm, initial CO₂ concentration 50000 ppm, initial NaClO concentration 0.024 M, temperature 313 K, distributor diameter 1 mm)

| S. No. | Time (min) | NO removal efficiency (%) | SO₂ removal efficiency (%) | CO₂ removal efficiency (%) |
|---------------|-------------------|----------------------------------|--|--|
| 1 | 0 | 0.00 | 0.00 | 0.00 |
| 2 | 20 | 82.56 | 97.81 | 41.24 |
| 3 | 40 | 75.66 | 97.58 | 38.12 |
| 4 | 60 | 71.81 | 96.97 | 37.33 |
| 5 | 80 | 66.36 | 96.52 | 36.94 |
| 6 | 100 | 63.84 | 96.10 | 35.82 |
| 7 | 120 | 57.45 | 95.38 | 34.62 |
| 8 | 140 | 51.81 | 90.97 | 33.12 |
| 9 | 160 | 46.36 | 86.52 | 30.24 |
| 10 | 180 | 38.84 | 81.10 | 26.12 |
| 11 | 200 | 31.45 | 75.38 | 22.32 |

Table A25: Data for enthalpy change with temperature using NaClO/NH₃

| S. No. | Temperature (K) | -ΔH (SO ₂) (kJ·mol ⁻¹) | -ΔH (NO) (kJ·mol ⁻¹) |
|--------|-----------------|--|-------------------------------------|
| 1 | 303 | 819.17 | 503.70 |
| 2 | 313 | 821.50 | 503.86 |
| 3 | 323 | 823.82 | 504.02 |
| 4 | 333 | 826.14 | 504.18 |
| 5 | 343 | 828.47 | 504.34 |
| 6 | 353 | 830.79 | 504.50 |

Table A26: Data for Gibbs free energy change with temperature using NaClO/NH₃

| S. No. | Temperature (K) | -ΔG (SO ₂) (kJ·mol ⁻¹) | -ΔG (NO) (kJ·mol ⁻¹) |
|--------|-----------------|--|-------------------------------------|
| 1 | 303 | 913.98 | 409.20 |
| 2 | 313 | 999.36 | 400.74 |
| 3 | 323 | 1045.71 | 394.97 |
| 4 | 333 | 1080.95 | 389.96 |
| 5 | 343 | 1110.96 | 385.32 |
| 6 | 353 | 1137.98 | 380.87 |

Table A27: Data for estimation of equilibrium time in semi batch stirred with NaClO/NH₃ (initial SO₂ concentration 1807 ppm, initial NO concentration 1020 ppm, temperature 313 K, initial pH 5.5, NaClO concentration 0.032 M, mole ratio of NH₃ to NaClO 1)

| S. No. | Time (min) | NO removal efficiency (%) | SO ₂ removal efficiency (%) |
|--------|------------|---------------------------|--|
| 1 | 0 | 0 | 0 |
| 2 | 5 | 52.83 | 98.25 |
| 3 | 10 | 75.24 | 98.24 |
| 4 | 15 | 83.86 | 97.92 |
| 5 | 20 | 89.21 | 97.12 |
| 6 | 25 | 91.25 | 98.87 |
| 7 | 30 | 91.39 | 99.15 |
| 8 | 35 | 92.23 | 99.45 |
| 9 | 40 | 91.86 | 99.42 |
| 10 | 50 | 91.96 | 99.23 |
| 11 | 60 | 92.24 | 99.14 |
| 12 | 70 | 91.43 | 98.23 |
| 13 | 80 | 91.56 | 98.56 |
| 14 | 90 | 92.03 | 98.42 |
| 15 | 100 | 91.85 | 98.41 |

| | | | |
|-----------|-----|-------|-------|
| 16 | 110 | 91.53 | 98.23 |
| 17 | 120 | 91.08 | 98.15 |
| 18 | 130 | 91.13 | 98.65 |
| 19 | 140 | 91.42 | 98.1 |
| 20 | 150 | 90.43 | 97.45 |
| 21 | 160 | 90.12 | 97.86 |
| 22 | 170 | 90.21 | 97.12 |
| 23 | 180 | 90.1 | 97.02 |
| 24 | 190 | 87.43 | 95.14 |
| 25 | 200 | 81.45 | 93.65 |
| 26 | 210 | 73.84 | 91.23 |
| 27 | 220 | 65.12 | 86.14 |
| 28 | 220 | 59.46 | 84.12 |
| 29 | 230 | 51.78 | 81.23 |
| 30 | 240 | 42.43 | 78.96 |
| 31 | 250 | 30.06 | 73.43 |
| 32 | 260 | 17.85 | 68.59 |
| 33 | 270 | 9.58 | 61.32 |
| 34 | 280 | 2.32 | 58.23 |
| 35 | 290 | 0 | 54.12 |
| 36 | 300 | 0 | 50.13 |

| | | | |
|-----------|-----|---|-------|
| 37 | 310 | 0 | 46.75 |
| 38 | 320 | 0 | 40.39 |
| 39 | 330 | 0 | 34.67 |
| 40 | 340 | 0 | 29.13 |
| 41 | 350 | 0 | 23.48 |
| 42 | 360 | 0 | 18.25 |
| 43 | 370 | 0 | 13.56 |
| 44 | 380 | 0 | 10.45 |
| 45 | 390 | 0 | 5.32 |
| 46 | 400 | 0 | 2.89 |
| 47 | 410 | 0 | 1.24 |
| 48 | 420 | 0 | 0 |

Table A28: Data for estimation of optimal molar ratio in semi batch stirred with NaClO/NH₃ (initial SO₂ concentration 1807.58 ppm, initial NO concentration 1020.51 ppm, temperature 313 K, initial pH 5.5, NaClO concentration 0.032 M, time 180 min)

| S. No. | Mole ratio of NaClO/NH₃ | NO removal efficiency (%) | SO₂ removal efficiency (%) |
|---------------|---|----------------------------------|--|
| 1 | 0.08 | 75.43 | 95.62 |
| 2 | 0.15 | 77.28 | 95.89 |
| 3 | 0.23 | 80.14 | 96.48 |
| 4 | 0.30 | 83.56 | 97.82 |
| 5 | 0.38 | 88.53 | 98.56 |
| 6 | 0.46 | 90.42 | 98.32 |
| 7 | 0.53 | 90.25 | 98.16 |
| 8 | 0.61 | 91.23 | 98.53 |
| 9 | 0.68 | 91.86 | 98.46 |
| 10 | 0.76 | 92.13 | 98.31 |
| 11 | 0.84 | 92.48 | 98.43 |
| 12 | 0.91 | 92.43 | 98.25 |
| 13 | 0.99 | 93.65 | 98.68 |
| 14 | 1.06 | 93.42 | 98.64 |
| 15 | 1.14 | 93.13 | 98.13 |

| | | | |
|-----------|------|-------|-------|
| 16 | 1.22 | 93.03 | 97.43 |
| 17 | 1.29 | 92.77 | 97.16 |
| 18 | 1.37 | 92.56 | 96.73 |
| 19 | 1.44 | 92.34 | 96.30 |
| 20 | 1.52 | 90.65 | 95.88 |
| 21 | 1.60 | 89.85 | 95.45 |
| 22 | 1.67 | 88.86 | 95.03 |
| 23 | 1.75 | 88.13 | 89.25 |
| 24 | 1.82 | 87.42 | 87.83 |
| 25 | 1.90 | 86.43 | 84.25 |
| 26 | 1.98 | 85.86 | 82.42 |
| 27 | 2.05 | 85.12 | 80.32 |
| 28 | 2.13 | 83.89 | 78.42 |
| 29 | 2.20 | 83.59 | 77.52 |
| 30 | 2.28 | 82.85 | 75.86 |
| 31 | 2.35 | 82.11 | 75.54 |
| 32 | 2.43 | 81.37 | 75.22 |
| 33 | 2.51 | 80.63 | 74.90 |
| 34 | 2.58 | 79.90 | 74.58 |
| 35 | 2.66 | 79.16 | 74.26 |
| 36 | 2.73 | 78.42 | 73.94 |

| | | | |
|-----------|------|-------|-------|
| 37 | 2.81 | 77.68 | 73.62 |
| 38 | 2.89 | 76.94 | 73.30 |
| 39 | 2.96 | 76.21 | 72.98 |
| 40 | 3.04 | 75.47 | 72.66 |

Table A29: Data for estimation of optimal temperature in semi batch stirred with NaClO/NH₃ (initial SO₂ concentration 1807.58 ppm, initial NO concentration 1020.51 ppm, initial pH 5.5, NaClO concentration 0.032 M, time 180 min, mole ratio of NH₃ to NaClO 1)

| S. No. | Temperature (K) | NO removal efficiency (%) | SO₂ removal efficiency (%) |
|---------------|------------------------|----------------------------------|--|
| 1 | 283 | 78.96 | 97.14 |
| 2 | 293 | 83.14 | 98.16 |
| 3 | 303 | 88.42 | 98.56 |
| 4 | 313 | 91.89 | 99.45 |
| 5 | 323 | 91.12 | 98.89 |
| 6 | 333 | 87.42 | 97.25 |

Table A30: Data for estimation of optimal pH in semi batch stirred with NaClO/NH₃ (initial SO₂ concentration 1807.58 ppm, initial NO concentration 1020.51 ppm, temperature 313 K, NaClO concentration 0.032 M, time 180 min, mole ratio of NH₃ to NaClO 1)

| S. No. | pH | NO removal efficiency (%) | SO ₂ removal efficiency (%) |
|--------|-----|---------------------------|--|
| 1 | 3.5 | 69.83 | 96.74 |
| 2 | 4 | 74.25 | 97.38 |
| 3 | 4.5 | 79.12 | 97.89 |
| 4 | 5 | 85.78 | 98.41 |
| 5 | 5.5 | 92.14 | 99.13 |
| 6 | 6 | 90.81 | 99.24 |
| 7 | 6.5 | 88.12 | 99.02 |
| 8 | 7 | 82.23 | 99.01 |
| 9 | 7.5 | 80.23 | 98.52 |
| 10 | 8 | 77.25 | 98.25 |
| 11 | 8.5 | 75.23 | 98.21 |
| 12 | 9 | 71.25 | 98.45 |
| 13 | 9.5 | 70.25 | 97.82 |
| 14 | 10 | 70.12 | 98.35 |

Table A31: Data for removal efficiency with initial SO₂ concentration in semi batch stirred with NaClO/NH₃ (initial NO concentration 1020.51 ppm, temperature 313 K, NaClO concentration 0.032 M, initial pH 5.5, time 180 min, mole ratio of NH₃ to NaClO 1)

| S. No. | SO₂ concentration (ppm) | NO removal efficiency (%) | SO₂ removal efficiency (%) |
|---------------|---|----------------------------------|--|
| 1 | 214 | 92.84 | 99.12 |
| 2 | 428 | 92.42 | 98.25 |
| 3 | 615 | 91.89 | 99.45 |
| 4 | 843 | 92.13 | 99.01 |
| 5 | 1026 | 91.83 | 98.45 |
| 6 | 1202 | 90.89 | 98.42 |
| 7 | 1434 | 91.24 | 97.23 |
| 8 | 1617 | 92.89 | 97.56 |
| 9 | 1808 | 91.65 | 98.42 |
| 10 | 2087 | 90.84 | 99.21 |
| 11 | 3103 | 90.25 | 97.13 |
| 12 | 4265 | 90.42 | 96.14 |
| 13 | 5028 | 90.37 | 97.02 |
| 14 | 6043 | 86.24 | 96.89 |

| | | | |
|-----------|------|-------|-------|
| 15 | 7126 | 83.25 | 95.24 |
| 16 | 8216 | 80.12 | 92.35 |

Table A32: Data for removal efficiency with initial NO concentration in semi batch stirred with NaClO/NH₃ (initial SO₂ concentration 1807.58 ppm, temperature 313 K, NaClO concentration 0.032 M, initial pH 5.5, time 180 min, mole ratio of NH₃ to NaClO 1)

| S. No. | NO concentration (ppm) | NO removal efficiency (%) | SO₂ removal efficiency (%) |
|---------------|-------------------------------|----------------------------------|--|
| 1 | 200 | 88.32 | 98.81 |
| 2 | 421 | 89.89 | 97.62 |
| 3 | 663 | 92.92 | 96.97 |
| 4 | 821 | 92.48 | 96.52 |
| 5 | 1021 | 91.83 | 96.01 |
| 6 | 1276 | 90.95 | 96.53 |
| 7 | 1412 | 89.45 | 96.28 |
| 8 | 1626 | 89.58 | 95.14 |
| 9 | 1845 | 88.64 | 95.23 |

Table A33: Data for NO removal efficiency change in both semi batch and spray column with NaClO/NH₃

| S. No. | Parameters | Semi Batch | Spray |
|---------------|-------------------------------|-------------------|--------------|
| 1 | SO ₂ concentration | 92.89 | 89.42 |
| 2 | NO concentration | 92.92 | 88.13 |
| 3 | Temperature | 91.89 | 87.28 |
| 4 | Mole ratio | 93.65 | 89.35 |
| 5 | Time | 92.24 | 88.13 |
| 6. | Average removal efficiency | 92.72 | 88.46 |
| 7. | Removal drop | | 4.59 |

Table A34: Data for SO₂ removal efficiency change in both semi batch and spray column with NaClO/NH₃

| S. No. | Parameter | Semi Batch | Spray |
|---------------|-------------------------------|-------------------|--------------|
| 1 | SO ₂ concentration | 99.45 | 98.23 |
| 2 | NO concentration | 98.81 | 97.24 |
| 3 | Temperature | 99.45 | 97.89 |
| 4 | Mole ratio | 98.68 | 96.98 |
| 5 | Time | 99.45 | 98.02 |
| 6. | Average removal efficiency | 99.17 | 97.67 |
| 7. | Removal drop | | 1.51 |

Appendix B

Table B1: Standard Gibbs free energy, enthalpy, entropy change and specific heat capacities of the components (**Dean 1970**)

| S. No. | Species | Physical State | ΔH , $\text{kJ}\cdot\text{mol}^{-1}$ | ΔG° , $\text{kJ}\cdot\text{mol}^{-1}$ | ΔS° , $\text{J}\cdot\text{K}^{-1}$ mol^{-1} | ΔC_p , $\text{J}\cdot\text{K}^{-1}$ mol^{-1} |
|--------|------------------------------------|----------------|---|---|--|---|
| 1. | SO ₂ | g | -296.81 | -300.13 | -248.223 | 39.88 |
| 2. | NO | g | 91.29 | 87.60 | 210.76 | 29.85 |
| 3. | HClO standard state | aq. | -120.9 | 79.9 | 142 | 37.15 |
| 4. | NaClO standard state | aq. | -347 | -298 | 100 | |
| 5. | NaCl standard State | aq. | -407.27 | -393.17 | 115.5 | -90.0 |
| 6. | Na ₂ SO ₄ | aq | -1387 | -1270.2 | 149.6 | 128.2 |
| 7. | NaNO ₃ | aq. | -1389.51 | -1268.40 | -138.1 | -201 |
| 8. | Cl ₂ | g | 0 | 0 | 233 | 33.95 |
| 9. | H ₂ O | l | -285.8 | -237.14 | 69.95 | 75.28 |
| 10. | SO ₄ ⁻² | aq. | -909.34 | -744.5 | 18.50 | -293.0 |
| 11. | NO ₃ ⁻ (aq.) | aq. | -206.85 | -111.3 | 146.70 | -86.6 |

| | | | | | | |
|------------|--|-----|---------|--------|--------|--------|
| 12. | Cl ⁻ standard state (aq.) | aq. | -167.08 | -131.3 | 56.60 | -136.4 |
| 14. | NH ₄ ⁺ standard state (aq.) | aq. | -133.26 | -79.37 | 111.17 | 79.9 |
| 15. | NH ₄ OH standard state (aq.) | aq. | -361.2 | -254.0 | 165.5 | -68.6 |

Appendix C

Table C1: Data for removal efficiency with initial SO₂ concentration using NaClO in bubble column (initial NO concentration 1804 ppm, initial pH 5.6, initial NaClO concentration 0.032 M, temperature 305 K, Time 2 h)

| S. No. | SO ₂ concentration (ppm) | NO removal efficiency (%) | SO ₂ removal efficiency (%) |
|--------|--|------------------------------|---|
| 1 | 4324 | 86.18 | 99.12 |
| 2 | 5481 | 88.23 | 99.14 |
| 3 | 6348 | 91.46 | 99.28 |
| 4 | 7238 | 92.26 | 99.73 |

Table C2: Data for removal efficiency with initial NO concentration using NaClO in bubble column (initial SO₂ concentration 6348 ppm, initial pH 5.6, initial NaClO concentration 0.032 M, temperature 305 K, Time 2 h)

| S. No. | NO concentration (ppm) | NO removal efficiency (%) | SO ₂ removal efficiency (%) |
|--------|---------------------------|------------------------------|---|
| 1 | 1456 | 88.10 | 99.52 |

| | | | |
|---|------|-------|-------|
| 2 | 1702 | 89.59 | 99.67 |
| 3 | 1804 | 91.01 | 99.76 |
| 4 | 1941 | 91.29 | 99.81 |

Table C3: Data for removal efficiency with initial pH of NaClO in bubble column (initial SO₂ concentration 6348 ppm, initial NO concentration 1804 ppm, initial NaClO concentration 0.032 M, temperature 305 K, time 2 h)

| S. No. | Initial pH | NO removal efficiency (%) | SO ₂ removal efficiency (%) |
|--------|------------|---------------------------|--|
| 1 | 4.3 | 87.28 | 99.41 |
| 2 | 5.1 | 90.81 | 99.73 |
| 3 | 5.6 | 91.62 | 99.82 |
| 4 | 6.4 | 87.67 | 99.88 |
| 5 | 7.9 | 80.25 | 99.91 |
| 6 | 9.1 | 62.42 | 99.49 |
