CHAPTER 5
EFFECT OF SIBX/TTC MIXTURES ON SINGLE-POINT BATCH FLOTATION

5.1 Introduction

This section presents experiments that were conducted in order to study the flotation response of sulphur, gold and uranium to substitution of SIBX with C_{10} or C_{12} TTC. The percent replacement of the standard (20g/t SIBX) was expressed on a molar basis. For each combination, both SIBX and TTC were dosed from 1%wt stock solutions, the volumes of which are shown in Tables 5.1 and 5.2. These were all calculated for a 2kg-dry ore sample used per batch flotation experiment. As in previous experiments, SIBX/TTC mole ratios were tested at pH 7.2, 16g/t Dowfroth 200, 70g/t CuSO4.5H_2O, 20g/t GEMPOLY GM4 and 6 minutes of flotation

Table 5.1 *SIBX/C_{10} TTC combinations and their corresponding reagent volumes*

Test	SIBX			C_{10} TTC		
	%	µmol	1% wt Solution (ml)	%	µmol	1% wt Solution (ml)
1	100	233	4.0	0	0	0.0
2	92	214	3.7	8	19	0.5
3	84	195	3.4	16	37	1.0
4	75	174	3.0	25	58	1.6

Table 5.2 *SIBX/C_{12} TTC combinations and their corresponding reagent volumes*

Test	SIBX			C_{12} TTC		
	%	µmol	1% wt Solution (ml)	%	µmol	1% wt Solution (ml)
1	100	233	4.0	0	0	0.0
2	92	214	3.7	8	19	0.6
3	84	195	3.4	16	37	1.1
4	75	174	3.0	25	58	1.7

5.2 SIBX and C_{10} TTC

5.2.1 Results and Discussion

Flotation responses to the different SIBX/C_{10} TTC combinations tested are shown in Tables 5.3 to 5.6 and Figures 5.1 to 5.6.

5.2.1.1 Mass Recovery

Table 5.3 shows mass recoveries for the SIBX/C10 TTC mole ratios tested. There was no significant variation with mole percent TTC dosed (Figure 5.1).

Table 5.3 *Mass recovery*

C_{10} TTC *(mole percent)*	Mass Recovery *(%)*	Standard Error
0	3.21	0.06
8	3.27	0.05
16	3.27	0.07
25	3.36	0.03

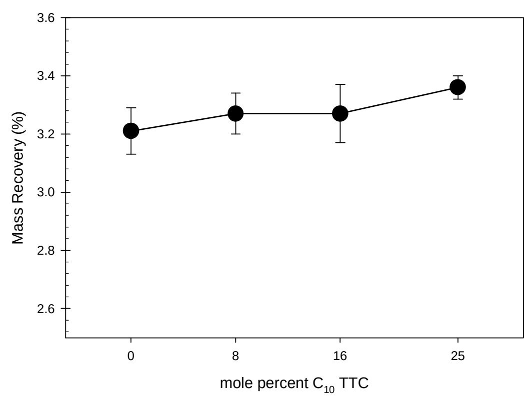

Figure 5.1 *Variation of mass recovery with mole percent of C_{10} TTC*

5.2.1.2 Sulphur

Concentrate and tailings sulphur grades and recoveries are shown in Table 5.4 below. Even though sulphur grade decreased with each increase in C_{10} TTC mole ratio dosed, the change was small (Figure 5.2 (a)). Sulphur recovery however increased from the standard (0 mole percent TTC) to 8 mole percent TTC, after which it decreased at 16 mole percent and increased again at 25 mole percent TTC (Figure 5.2(b)).

Table 5.4 *Sulphur flotation responses for SIBX/C_{10} TTC mole ratios tested*

C_{10} TTC *(mole percent)*	Concentrates		Tails		Sulphur Recovery (%)	Std Error
	Sulphur Grade (%)	Std Error	Sulphur Grade (%)	Std Error		
0	25.12	0.41	0.23	0.00	78.64	0.03
8	24.77	0.50	0.21	0.00	79.40	0.35
16	24.84	0.66	0.23	0.00	78.17	0.11
25	24.06	0.24	0.22	0.00	78.91	0.03

Sulphur flotation response is best illustrated in Figure 5.3. All the collector mixtures gave almost similar effects. The difference between the highest recovery (at 8 mole percent TTC) and the lowest (at 16 mole percent TTC) is only 1.23%. Regardless of this, it appears that 8 mole percent TTC gave the highest sulphur recovery and hence the best performance. This was followed by 25 mole percent TTC, the standard and lastly 16 mole percent TTC.

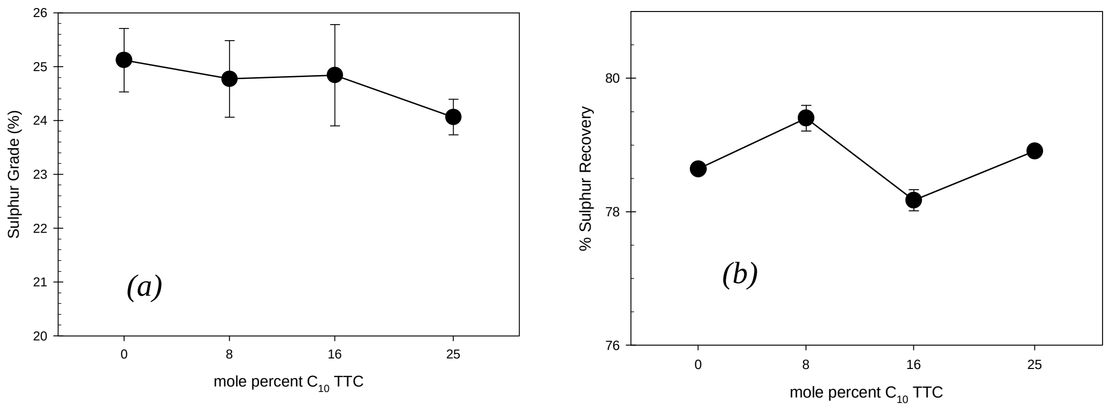

Figure 5.2 *Variation of (a) sulphur grade (b) sulphur recovery with C_{10} TTC mole ratio*

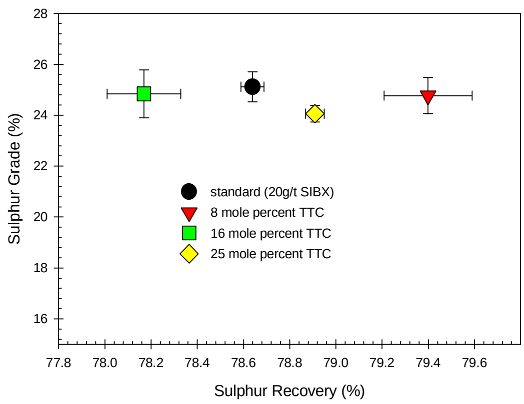

Figure 5.3 *Sulphur grade-recovery combinations for the different SIBX/C_{10} TTC mixtures tested*

5.2.1.3 Uranium

Table 5.5 shows uranium flotation responses. Uranium grades showed a peak at 8 mole percent C_{10} TTC (Figure 5.4 *(a)*). This was followed by a decline to almost identical responses at both 16 mole percent and 25 mole percent TTC. The recoveries however showed small increases each time more TTC was added (Figure 5.4 (b)). An assessment of Figure 5.4 (c) shows that all C_{10} TTC /SIBX mixtures gave higher recoveries than the standard. This could have been a result of synergism between TTC and SIBX. 8 mole percent TTC gave the highest grade of 721.5ppm while 25 mole percent TTC recorded the highest recovery of 15.6%.

Table 5.5 *Uranium flotation responses for the SIBX/C_{10} TTC combinations tested*

C_{10} TTC (*mole percent*)	Concentrates		Tails		Uranium Recovery (%)	Std Error
	Uranium (*ppm*)	Std Error	Uranium Grade (*ppm*)	Std Error		
0	696.67	12.66	143.00	3.24	13.92	0.09
8	721.50	16.19	136.00	5.79	14.65	0.44
16	682.67	14.72	137.67	2.94	14.36	0.14
25	692.67	5.31	130.33	1.08	15.60	0.08

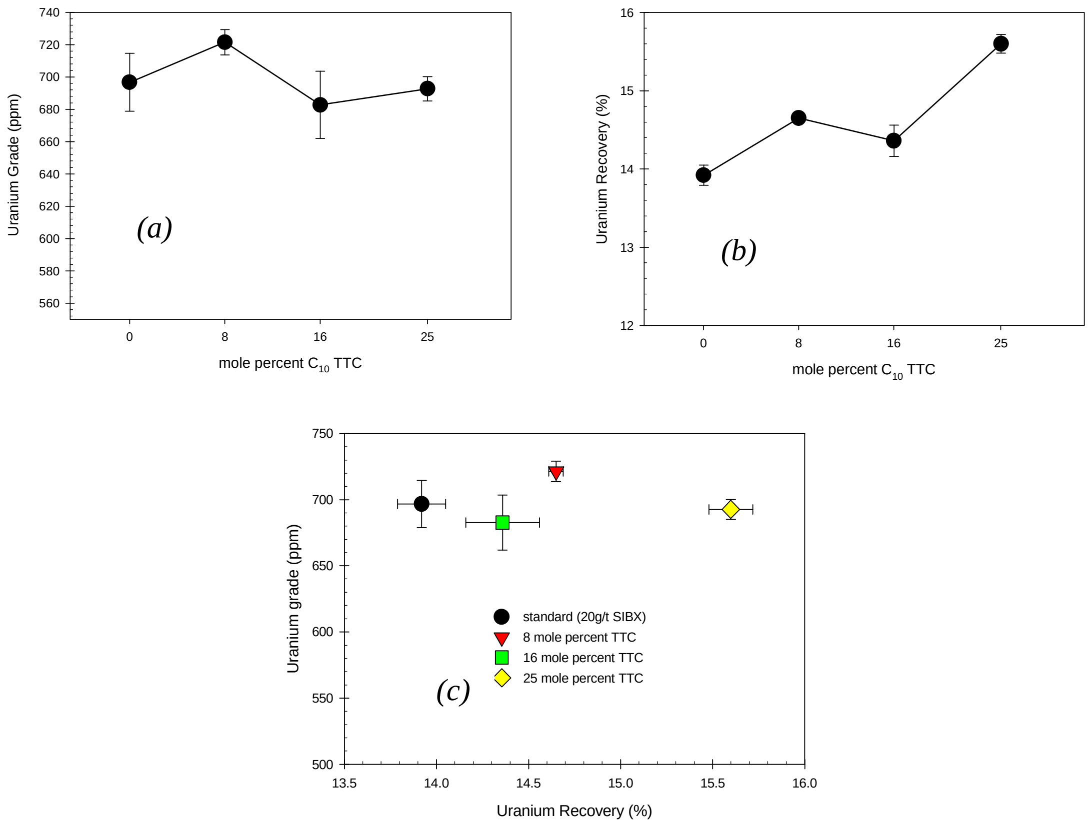

Fig. 5.4 *Response of (a) uranium grade and (b) uranium recovery to different SIBX/ C_{10} TTC mixtures. (c) Corresponding uranium grade–recovery relationships*

The best performance came from 25 mole percent TTC, which recovered 15.6% of uranium in the feed compared to 13.92% of the standard. This collector combination is in agreement with the findings reported by Davidtz

(2002). At this same point, the mass recovery rose from 3.21% to 3.36%. As for the grade, it fell marginally from 696.7ppm to 692.7ppm. This suggests that the increase in recovery might have been due to an improvement in the collecting power of the "collector" instead of being merely due to an increase in mass yield. Had this been the case, an increase in mass recovery is supposed to have reduced the grade by a reasonable magnitude. More uranium was indeed recovered by a combination of 25 mole percent C_{10} TTC than with SIBX on its own.

5.2.1.4 Gold

Gold flotation responses are shown in Table 5.6. The standard gave the highest grade, which decreased as more TTC was added (Figure 5.5 (a)). Recovery on the other hand increased continuously from the standard to 25 mole percent (Figure 5.5 (b)). The difference between the flotation responses at 16 and at 25 mole percent TTC was marginal (Figure 5.6).

Table 5.6 *Gold flotation data for SIBX/C_{10} TTC mixtures tested*

C_{10} TTC *(mole percent)*	Concentrates		Tails		Gold Recovery *(%)*	Std Error
	Gold Grade *(g/t)*	Std Error	Gold Grade *(g/t)*	Std Error		
0	5.43	0.04	0.21	0.01	38.21	1.30
8	5.40	0.22	0.26	0.01	40.51	0.13
16	5.20	0.07	0.24	0.01	42.66	0.74
25	5.00	0.14	0.23	0.01	43.45	1.34

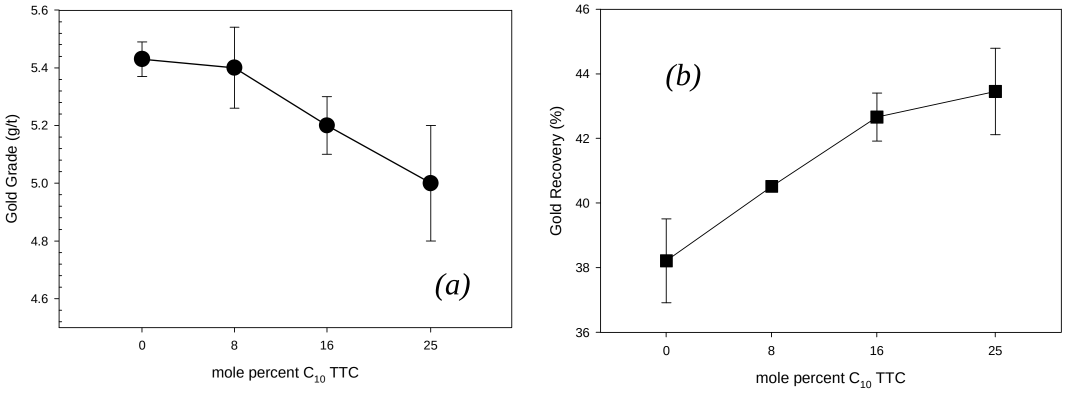

Fig. 5.5 *(a) Gold grade and (b) recovery for SIBX/C*$_{10}$ *TTC mixtures*

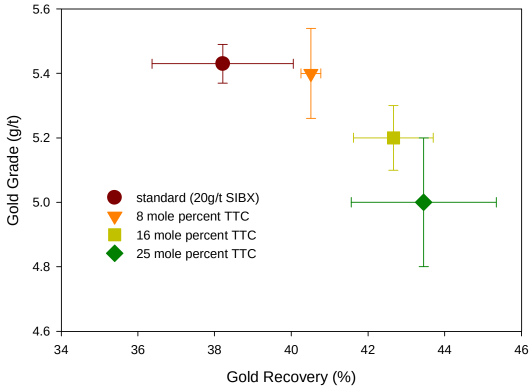

Figure 5.6 *Gold grade–recovery relationships for SIBX/C*$_{10}$ *TTC combinations*

5.2.1.5 Conclusions

The highest sulphur recovery was recorded at 8 mole percent TTC. Both uranium and gold recoveries increased with TTC mole percent, to give their highest readings at 25 mole percent TTC.

5.3 SIBX and C_{12} TTC

5.3.1 Results and Discussion

The flotation results recorded for the various SIBX–C_{12} TTC combinations tested are shown in Tables 5.7 to 5.10 and Figures 5.7 to 5.11. The same conditions of pH, frother, activator and depressant as previously used apply

5.3.1.1 Mass Recovery

The mass recoveries recorded for all the SIBX/C_{12} TTC mixtures are shown in Table 5.7. A plot of these results in Figure 5.7 shows that mass recovery increased as the mole percent of C_{12} TTC in the collector mixture was increased. As in the case of C_{10} TTC/SIBX mixtures, this can be attributed to the increasing concentrations of a TTC collector that has more selectivity towards sulphides because of three sulphur atoms in its functional group that have a high affinity for metal ions on the minerals (Davidtz, 2005). Due to its long chain, the collector also has poor selectivity towards gangue (Fuerstenau, 1982b), which increases its flotation, and hence mass recovery.

Table 5.7 *Mass recovery*

C_{12} TTC (*mole percent)*	Mass Recovery *(%)*	Standard Error
0	3.20	0.06
8	3.31	0.03
16	3.41	0.10
25	3.46	0.12

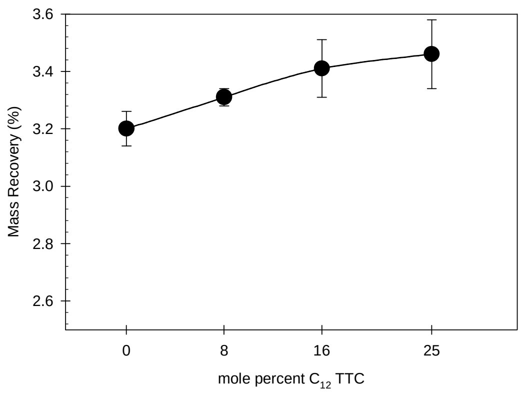

Figure 5.7 *Response of mass recovery to increased C_{12} TTC mole percent*

5.3.1.2 Sulphur

Sulphur flotation responses are shown in Table 5.8. Sulphur grade generally decreased with increases in C_{12} TTC mole percent used in the collector mixture (Figure 5.8 (a)). This can be accounted for using mass recoveries (Figure 5.7), which took an opposite trend. According to Fuerstenau (1982b), long chain collectors are known to exhibit poor selectivity so that increased mass recoveries result. This in turn implies that more gangue is floated and the concentrate grade falls. Sulphur recoveries were not significantly affected within the SIBX/TTC mole ratios tested (Figure 5.8 (b))

Table 5.8 *Sulphur flotation responses for SIBX/C_{12} TTC mole ratios*

C_{12} TTC (*mole percent*)	Concentrates		Tails		Sulphur Recovery (%)	Std Error
	Sulphur Grade (%)	Std Error	Sulphur Grade (%)	Std Error		
0	25.7	0.29	0.22	0.01	79.3	0.8
8	25.3	0.44	0.22	0.00	79.7	0.3
16	24.7	0.78	0.22	0.00	79.6	0.2
25	24.3	0.73	0.23	0.01	79.2	0.5

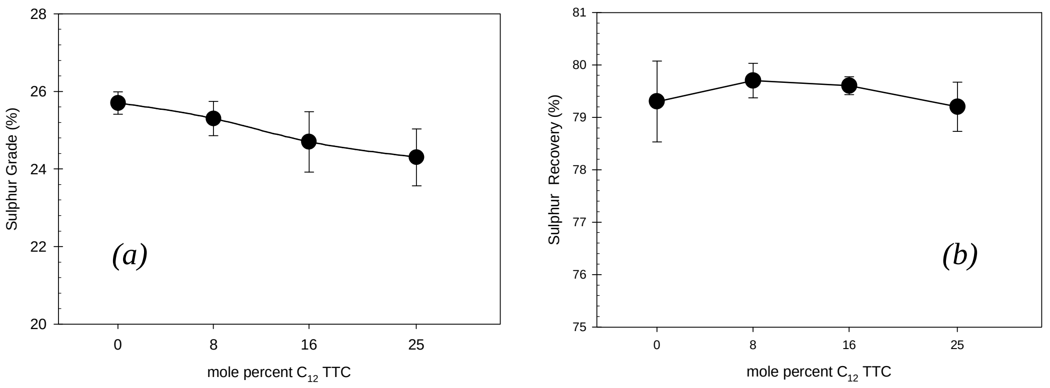

Figure 5.8 *Sulphur (a) grade and (b) recovery plotted against C_{12} TTC mole percent in the collector mixture*

5.3.1.3 Gold

Gold flotation responses are shown in Table 5.9. Grades fell at the onset of C_{12} TTC addition (Figure 5.9 (a)). Since this behaviour was not accompanied by a drop in recovery, it might have been caused by the poor selectivity of the long chain C_{12} collector towards gangue.

Table 5.9 *Gold flotation data for SIBX/C_{12} TTC mixtures*

C_{12} TTC *(mole percent)*	Concentrates		Tails		Gold Recovery (%)	Std Error
	Gold Grade *(g/t)*	Std Error	Gold Grade *(g/t)*	Std Error		
0	5.1	0.1	0.24	0.02	39.0	0.68
8	5.0	0.2	0.24	0.00	41.6	1.45
16	4.9	0.2	0.22	0.01	43.5	1.25
25	4.7	0.2	0.21	0.01	45.3	1.18

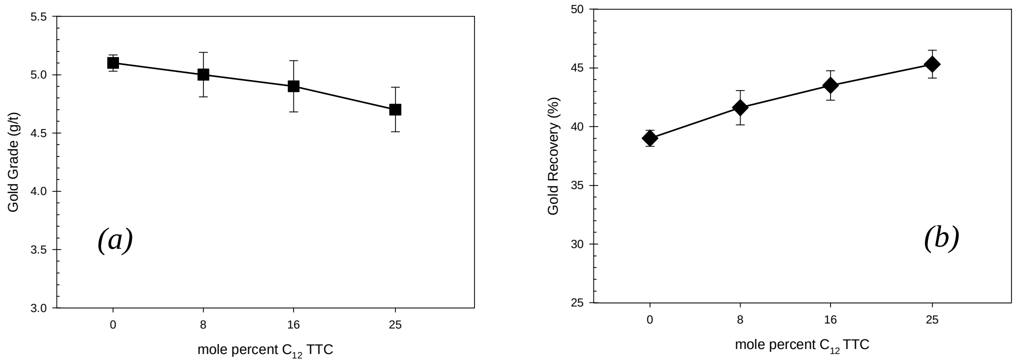

Figure 5.9 *Response of gold (a) grade, and (b) gold recovery change in C_{12} TTC mole percent in the collector*

Recovery on the other hand improved as the mole fraction of TTC dosed was increased (Figure 5.9 (b)), giving the highest response at 25 mole percent TTC. From Figure 5.10, it can be seen that the standard gave the highest grade of 5.1g/t. As the mole percent TTC dosed was increased, grade decreased and recovery increased, reaching a maximum of 45.3% at 25 mole percent TTC. At this point, the grade had fallen to 4.7g/t. These progressive increases in recovery could be a result of synergism between SIBX and C_{12} TTC. Introduction of 8 mole percent TTC increased recovery by a factor of 6% whereas 25 mole percent increased it by 16%.

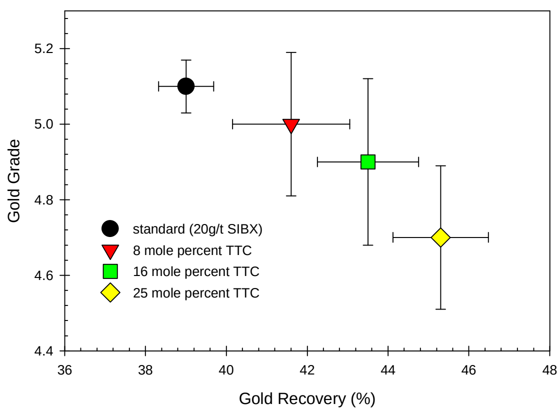

Figure 5.10 *Gold recoveries and their corresponding grades for SIBX/C_{12} mixtures*

5.3.1.4 Uranium

Table 5.10 shows uranium flotation responses. Both grade and recovery did not show any significant change with TTC concentration in the collector (Figure 5.11). These results all show poor flotability of uranium bearing minerals under the prevailing conditions at least.

Table 5.10 *Uranium flotation responses for different SIBX/C_{12} TTC mixtures*

C_{12} TTC (*mole percent*)	Concentrates		Tails		Uranium Recovery (%)	Std Error
	Uranium (*ppm*)	Std Error	Uranium Grade (*ppm*)	Std Error		
0	822.3	61.6	142.0	3.9	16.1	1.3
8	771.7	32.1	136.0	11.4	16.4	1.1
16	729.0	15.1	133.7	7.8	16.2	0.6
25	714.0	27.0	142.7	1.8	15.2	0.9

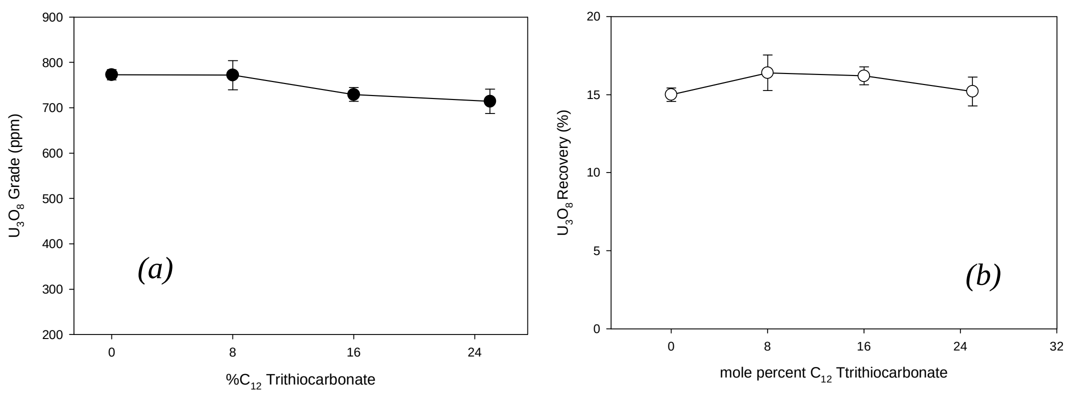

Figure 5.11 *Response of uranium (a) grade and (b) recovery to change in C_{12} TTC mole percent in the collector mixture dosed*

5.3.1.5 Conclusions

Mass recoveries increased as the TTC mole percent in the collector mixture was increased. Sulphur and uranium recoveries did not change significantly while gold recoveries increased steadily to give the highest response at 25 mole percent TTC.

In all the flotation responses of SIBX/TTC mixtures presented so far, commercial TTC (20% wt TTC) was diluted to 1% wt stock solutions, which were used within 24 hours of preparation. It later emerged that TTC is stabilised by high pH and the decrease in pH that comes with dilution could have resulted in hydrolysis, reducing its activity (Davidtz, 2005). This necessitated the testing of fresh TTC to establish sulphur, gold and pyrite flotation responses. In the next section, C_{12} TTC was chosen for the purpose.

5.4 Auriferous Pyrite Flotation with SIBX/Fresh C_{12} TTC Mixtures

5.4.1 Introduction

In this section, single-point batch flotation experiments testing the effect of fresh C_{12} TTC/SIBX mixtures on auriferous pyrite, gold and uranium flotation are presented. In section 5.3, C_{12} TTC was diluted to a 1% wt solution before use. Its pH fell from 12.04 to 11.47 on dilution. Work conducted by Viljoen (1998) showed a half-life of 30 minutes for *i*C3 TTC at pH 6. Even though the pH of the 1% wt C_{12} TTC stock solution used in this present work did not fall this low, there is a possibility that activity could have been lost on dilution. A re-run of the experiments was therefore conducted. New feed material from No 2 Plant was used. Comparison between the XRD pattern of this ore and that used in earlier experiments (Figure 2.1) shows that they possess identical mineralogical compositions

As in the previous experiments, the percent replacement of the standard 20g/t SIBX has been expressed on a molar basis. SIBX and TTC were dosed according to Table 5.11, the values being calculated for a 2kg-dry ore sample used per batch test. All experiments were conducted at pH 7.2, 16g/t Dowfroth 200, 70g/t $CuSO4.5H_2O$, 20g/t GEMPOLY GM4 and 6 minutes of flotation

Table 5.11 *SIBX/C_{12} TTC combinations and their corresponding reagent volumes*

Test	SIBX			C_{12} TTC		
	%	µmol	1% wt Solution (ml)	%	µmol	20% wt Commercial TTC (µL)
1	100	233	4.0	0	0	0
2	92	214	3.7	8	19	27907
3	84	195	3.4	16	37	55814
4	75	174	3.0	25	58	87209

5.4.2 Results and Discussion

The flotation responses for the different SIBX/C_{12} TTC mixtures tested are shown in Tables 5.12 to 5.16 and Figures 5.12 to 5.18.

5.4.2.1 Water Recovery

Water recoveries recorded for SIBX/C_{12} TTC mixtures tested for their effect on auriferous pyrite flotation are shown in Table 5.12. A plot of this data against mole percent TTC shows an increase from the standard to eight mole percent (Figure 5.12). From this point forward, the change is not significant.

Table 5.12 *Water recoveries*

C_{12} TTC (*mole percent*)	Water Recovery (*g*)	Standard Error
0	229.4	3.8
8	297.7	16.9
16	301.7	4.5
25	300.0	24.0

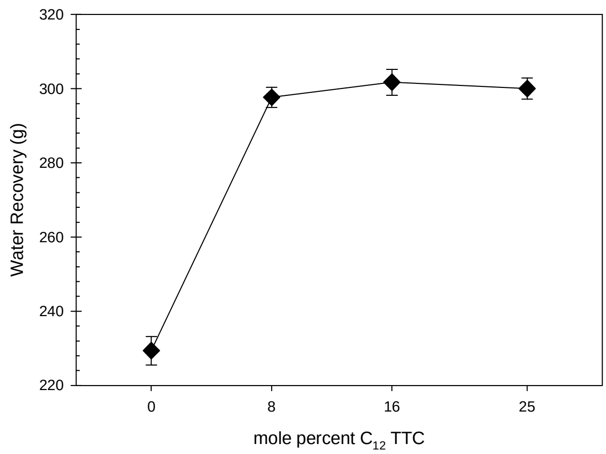

Figure 5.12 *The response of water recovery to mole percent C_{12} TTC*

The water recovery for the standard is considerably lower than that for the eight mole percent C_{12} TTC mixture by 29.8%. Since Kirjavainen (1996) has shown that water recoveries can be used as an indication of gangue flotation by entrainment, all the SIBX/TTC mixtures are likely to give higher mass recoveries and hence lower concentrate grades than the standard.

5.4.2.2 Mass Recovery

The mass recoveries recorded for SIBX/C_{12} TTC combinations tested are shown in Table 5.13. A graph plotted from these data shows an increase from the standard to eight mole percent TTC (Figure 5.13(a)). The trend appears to be similar to that observed in Figure 5.12. In fact, mass recovery plotted against water recovery shows a strong correlation (Figure 5.13 (b)). This means that higher mass recoveries for all TTC mixtures could be attributed to gangue flotation since gangue entrainment is directly proportional to the water recovery.

Table 5.13 *Mass recovery*

C_{12} TTC (*mole percent*)	Mass Recovery (%)	Standard Error
0	2.78	0.11
8	3.34	0.07
16	3.38	0.07
25	3.35	0.20

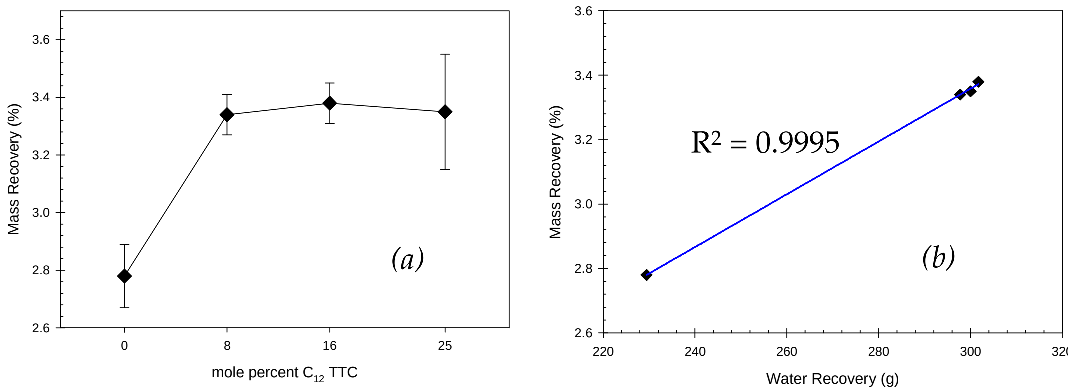

Figure 5.13 *Variation of mass recovery with mole percent C_{12} TTC of the mixture dosed and (b) linear relationship between mass and water recoveries*

5.4.2.3 Sulphur

Sulphur flotation responses for SIBX/C_{12} TTC mixtures are shown in Table 5.14. A plot of sulphur grade versus TTC mole percent shows a progressive decrease from the standard onwards (Figure 5.14 (a)). With the three SIBX/TTC mixtures exhibiting almost similar responses, the trend is opposite to that taken by mass recovery (Figure 5.13 (a)). The strong correlation shown in Figure 5.14 (b) suggests that the decrease in grade was a result of higher mass recovery, which is related to water recovery (Figure 5.13 (b)).

Table 5.14 *Sulphur flotation responses for SIBX/C_{12} TTC mixtures tested*

C_{12} TTC (*mole percent*)	Concentrates		Tails		Sulphur Recovery (%)	Std Error
	Sulphur Grade (%)	Std Error	Sulphur Grade (%)	Std Error		
0	25.8	0.5	0.4	0.01	67.7	0.1
8	22.3	0.2	0.4	0.02	67.8	1.2
16	22.0	0.1	0.4	0.01	64.4	0.1
25	21.2	0.7	0.4	0.00	66.6	0.6

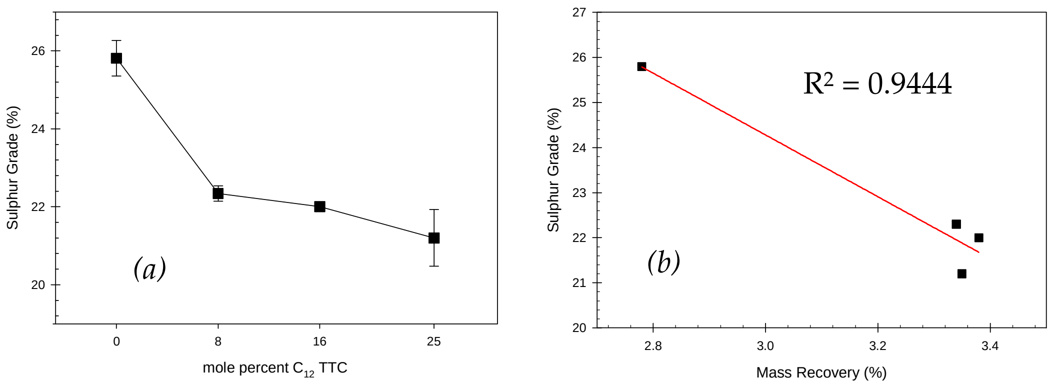

Figure 5.14 *(a) Sulphur grade responses to amount of TTC dosed and (b) the linear relationship between sulphur grade and mass recovery*

Sulphur recovery did not show significant change with TTC mole percent (Figure 5.15 (a)). This means that the increase in mass recovery that was accompanied by a decrease in sulphur grade was not due to more sulphide being floated. Since water recovery and mass recovery showed a correlation, the progressive decrease in sulphur grade and might have been due to increased gangue flotation. With the difference between the highest sulphur recovery and the lowest equal to 1.8%, sulphur flotation for all collector mixtures did not show any significant variation (Figure 5.15 (b)).

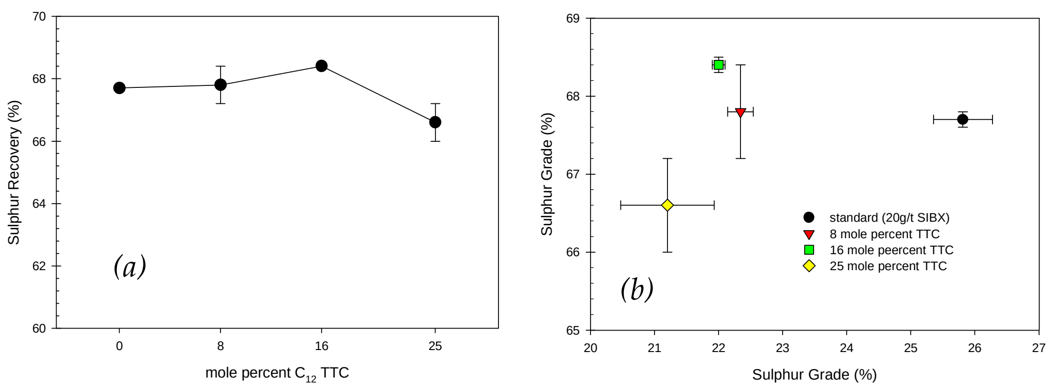

Figure 5.15 *(a) Response of sulphur recovery to mole percent TTC dosed (b) Sulphur recoveries and their corresponding grades for the different collector combinations*

5.4.2.4 Uranium

Uranium flotation responses are shown in Table 5.15. Plotting grade against reagent concentration shows a progressive decrease from the standard to twenty-five mole percent TTC (Figure 5.16 (a)). Based on a correlation with mass recovery (Figure 5.16 (b)), this trend might have been due to increased gangue flotation.

Table 5.15 *Uranium flotation responses for different SIBX/C_{12} TTC mixtures*

C_{12} TTC (*mole percent*)	Concentrates		Tails		Uranium Recovery (%)	Std Error
	Uranium (*ppm*)	Std Error	Uranium Grade (*ppm*)	Std Error		
0	1355	35.0	90.0	0.00	30.1	0.45
8	1230	30.0	90.0	0.00	32.1	0.26
16	1200	0.0	90.0	0.00	31.8	0.82
25	1140	40.0	90.0	0.00	30.5	0.76

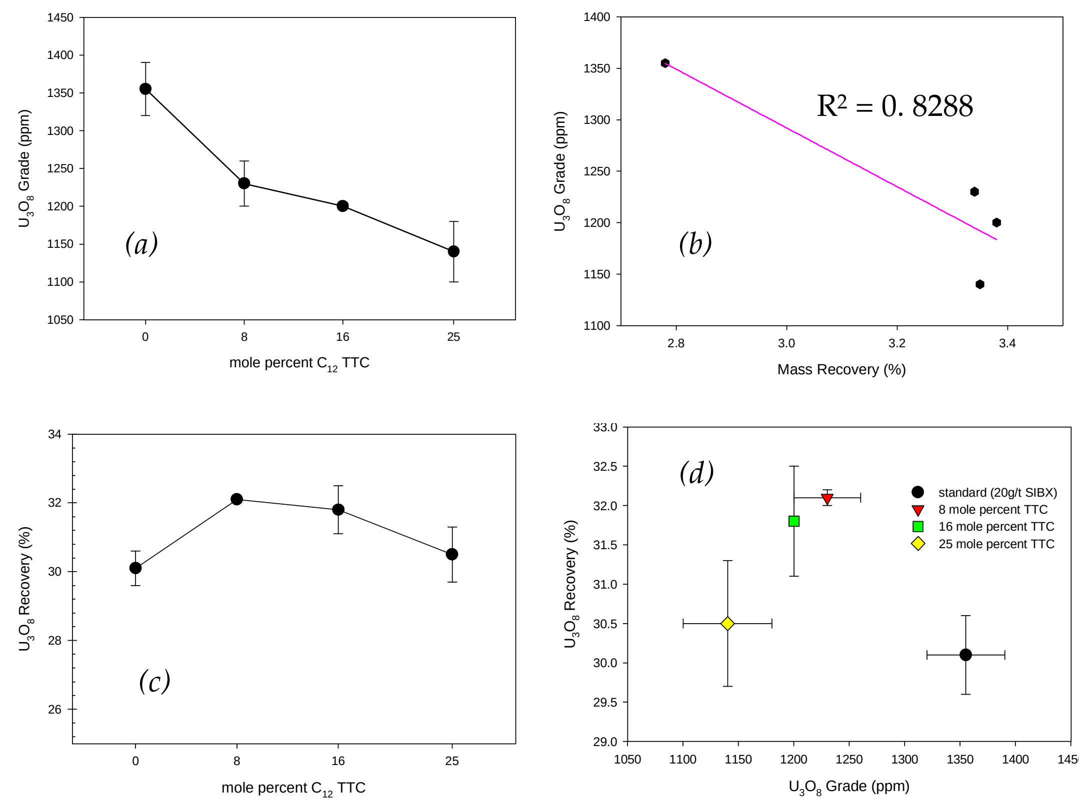

Figure 5.16 *(a) Variation of uranium grade with mole percent C_{12} TTC dosed, (b) linear correlation between uranium grade and mass recovery, (c) change in uranium recovery for varying TTC mole percent and (d) a summary of uranium flotation responses*

From the standard to eight mole percent TTC, uranium recovery increased by 6% (Figure 5.16 (c). Even though this appears small when experimental error is taken into account, a trend exists. Adjacent collector mixtures gave almost similar responses and both grade and recovery decreased as the mole percent of TTC in the collector mixture was increased (Figure 5.16 (d)). Eight and sixteen mole percent TTC gave higher recoveries than the standard, which could be attributed to synergy between SIBX and TTC. The decrease in recovery that followed at twenty-five mole percent is smaller than the associated experimental error and is therefore non-existent.

5.4.2.5 Gold

Table 5.16 shows gold recoveries, concentrate and tails grades recorded for the SIBX/C_{12} TTC mixtures tested. A plot of gold grade versus mole percent TTC shows a decrease from the standard to 8 mole percent (Figure 5.17 (a)). This is followed by almost similar responses from all three SIBX/TTC mixtures. The difference between the response of the standard and mixtures is most probably due to increased gangue recoveries. Between the standard and 8 mole percent TTC, gold recovery increased by a factor of 10.3% and it remained almost constant thereafter (Figure 5.17 (b)). The slight variation that followed was rendered insignificant by experimental error.

Table 5.16 *Gold flotation data for SIBX/C_{12} TTC mixtures tested*

C_{12} TTC (*mole percent*)	Concentrates		Tails		Gold Recovery (%)	Std Error
	Gold Grade (*g/t*)	Std Error	Gold Grade (*g/t*)	Std Error		
0	5.90	0.10	0.2	0.01	46.4	0.03
8	5.30	0.04	0.2	0.00	51.2	1.49
16	5.36	0.03	0.2	0.00	51.7	1.61
25	5.36	0.04	0.2	0.00	44.1	1.92

As can be deduced from Figure 5.18, all the three SIBX/mixtures gave similar gold grades and recoveries. Eight mole percent TTC can be viewed as an optimum because of its lower TTC requirement.

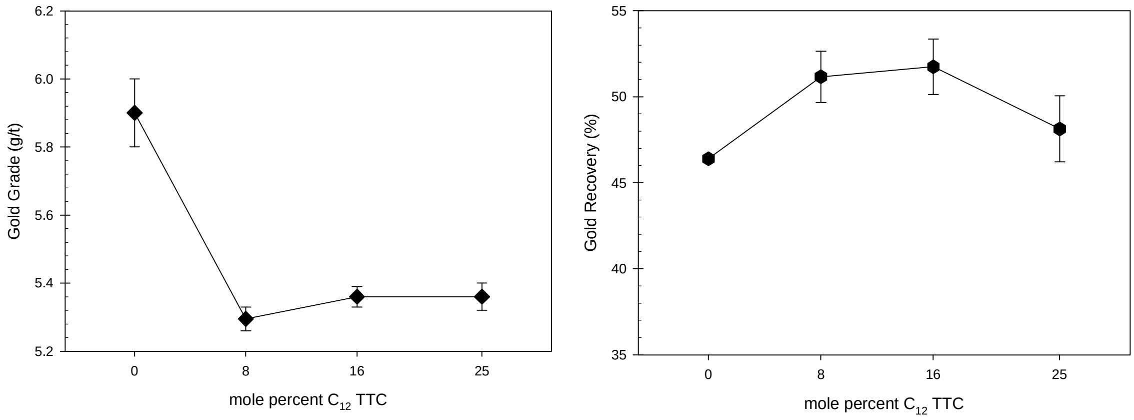

Figure 5.17 *Change in (a) gold grade and (b) gold recovery with mole percent C_{12} TTC*

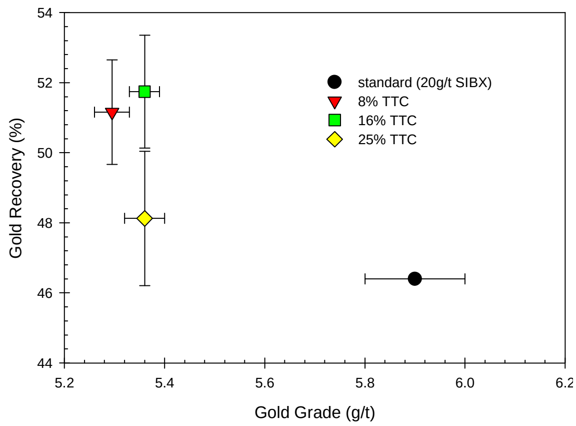

Figure 5.18 *A summary of gold flotation responses for the different collector mixtures tested*

5.4.2.6 Conclusions

All SIBX/C_{12} TTC mixtures showed almost similar mass and water recoveries and these were significantly higher than the standard. Sulphur recovery did not change significantly with TTC mole fraction while uranium and gold recoveries recorded highest values at 8 mole percent TTC.