Eco-friendly and versatile brominating reagent prepared from a liquid bromine precursor†

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Facile bromination of various organic substrates has been demonstrated with a 2 : 1 bromide:bromate reagent prepared from the alkaline intermediate of the conventional bromine recovery process. The reagent is acidified *in situ* to generate HOBr as the reactive species, which effects bromination. Aromatic substrates that have been successfully brominated under ambient conditions without use of any catalyst include phenols, anilines, aromatic ethers and even benzene. Non-aromatic compounds bearing active methylene group were monobrominated selectively with the present reagent and olefinic compounds were converted into the corresponding bromohydrins in moderate yields. By obtaining the present reagent from the liquid bromine precursor, the twin advantages of avoiding liquid bromine and producing the reagent in a cost-effective manner are realised. When coupled with the additional advantage of high bromine atom efficiency, the present protocol becomes attractive all the way from ''cradle to grave''.

1 Introduction

Bromo derivatives have wide utility both as products and intermediates.[1,2] Many of these compounds are prepared using liquid bromine. Liquid bromine is used both for addition reactions as well as for substitution reactions. Activated aromatic compounds, such as phenols, anilines, and aromatic ethers, can be brominated without a catalyst, even at relatively low temperatures,[3] whereas other substrates may demand use of a catalyst. Commonly used catalysts include halides of aluminum, iron, zinc, or antimony.[4] Liquid bromine is corrosive and its transport and handling pose difficulties. Moreover, substitution reactions with liquid bromine lead to only 50% bromine atom efficiency, although the HBr by-product can be recycled with oxidizing agents such as H_2O_2.[5] HBr can, alternatively, be recovered and sold, or used for co-production of alkyl bromides such as methyl bromide.[6]

Besides liquid bromine, there are latent brominating reagents, such as pyridiniumbromide-perbromide,[7] and quaternary ammonium tribromide,[8] which are safer and easier to use but such reagents are also produced using liquid bromine. Moreover, the bromine atom efficiency is only 50%. There are other brominating agents that are employed when the reactions either do not proceed with liquid bromine or proceed with low selectivity. Examples of such brominating agents include *N*-bromosuccinimide (NBS) for allylic bromination,[9] and 2,4,4,6-tetrabromo-2,5-cyclohexadien-1-one (TBCD) for monobromination with para-selectivity,[10] but in these cases their preparation also involves liquid bromine.[11] Other reagents reported for bromination of aromatic substrates include: Br_2–NaY zeolite and Br_2–alumina,[12] HBr–DMSO,[13] and P_2O_5–Bu_4NBr.[14] $NaBrO_3$–H_2SO_4 has been shown to be a promising reagent for bromination of aromatic rings having electron deactivating substituents.[15–19] $NaBrO_3$–HBr in sulfuric acid/acetic acid medium has been used for bromination of several amides and imides,[20a] while $NaBrO_3$–$NaHSO_3$ has been shown to be a good reagent for bromination of alkyl benzenes and for the synthesis of bromohydrins from alkenes.[20b,c] BrCl has also been used for substitution reactions and the reactions are reported to be faster than those involving bromine alone.[21] Even in these cases, the preparations of basic inorganic bromide salts and acids involve downstream reactions with liquid bromine followed by purification processes,[22] *i.e.*, liquid bromine is ubiquitous in the product life cycle of all the above bromination reactions. Given the hazards of liquid bromine, it is desirable to develop schemes that dispense with its use directly or indirectly.

2 Results and discussion

Bromine is manufactured from sea bittern. We have recently patented the preparation and utility of a brominating reagent obtained from the liquid bromine precursor in the ''cold process'' of bromine manufacture.[23] The precursor comprises a 5 : 1 mole ratio of NaBr:$NaBrO_3$, which is formed when bromine vapor evolved from bittern is trapped in aqueous NaOH. Instead of acidifying the precursor to evolve bromine as practiced in conventional manufacture (eqn 1), it is treated with Cl_2–NaOH (or NaOCl) to obtain a 2 : 1 mole ratio of

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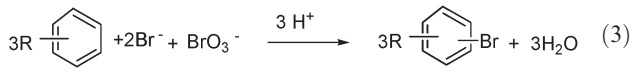
NaBr:$NaBrO_3$ (eqn 2), which can be used as such or evaporated to dryness to yield a solid reagent containing 40% (w/w) active Br.[24] The reagent, upon acidification with HCl[25] in the presence of an organic substrate, yields bromo derivative as per the stoichiometry of eqn 3. NaCl that is co-present in the reagent to the extent of 33% (w/w) does not affect the results, as confirmed through control experiments with a pure 2 : 1 mixture of NaBr:$NaBrO_3$.

$$5NaBr + NaBrO_3 + 6HCl \rightarrow 3Br_2 + 3H_2O + 6\ NaCl \quad (1)$$

$$5NaBr + NaBrO_3 + 3NaOCl \rightarrow 4NaBr + 2NaBrO_3 + 3NaCl \quad (2)$$



(3)

Table 1 shows the bromination of phenol and phenol derivatives undertaken with the present reagent system. All the reactions proceeded in high yields under ambient conditions and without recourse to any catalyst. Entries 1–3 were carried out with neat substrate, while CH_2Cl_2 was employed as solvent in the remaining reactions. Alternatively, 1,2-dichloroethane can also be used. In the case of reaction with bisphenol A—which yields the commercially important fire retardant tetrabromobisphenol A—the product is obtained directly in solid form in 98% purity and the mother liquor is recycled in subsequent batches resulting in high (92%) overall yield. Reaction calorimetric studies suggest that the reaction is near instantaneous with an adiabatic rise in temperature of only 18 °C, indicating that the bromination is facile and safe. We examined the efficacy of the reagent with aniline and its derivatives as well. The results are provided in Table 2. A molar excess of acid was used as the amine forms a salt with acid, which was neutralized with sodium bicarbonate after completion of the reaction. 2,4,6-Tribromoaniline could be prepared in 96% yield and 98.6% purity from aniline.

We also undertook reactions with other aromatic substrates. Monobromination of anisole and acetanilide was achieved in good yields and with high *p*-selectivity (entries 1 and 3, Table 3). Naphthalene could also be converted into 1-bromonaphthalene, albeit only in 36% isolated yield under the same conditions (others products of the reaction have not been characterised). With benzene the reaction was facile only under reflux conditions, and the yield was better (81.3% at 100 g scale; 95% purity by HPLC) when sodium lauryl sulfate (SLS) was used as a phase transfer catalyst.[23d]

We have also studied the monobromination of several CH-acidic compounds (Table 4). Whereas such selective bromination with conventional brominating agents is difficult,[26] the reactions could be achieved in good yields with the present reagent.[27–32] *N*-Bromosuccinimide, employed for allylic bromination, could also be synthesized with the present reagent prepared from the bromine intermediate.[20] The product is obtained directly in solid form when water is used as solvent, and the filtered mass is purified by washing with water to remove adhering impurities (yield 78%; purity 92%).

UV-visible spectroscopic studies helped us establish that, upon acidification of the reagent, BrOH is produced (λ_{max} = 260 nm), albeit with traces of elemental bromine.[33] We therefore explored the possible utility of the reagent for synthesis of bromohydrins.[20c,34] This was successfully accomplished as can be seen from Table 5. However, the dibromo derivative was inevitably formed as an impurity.

3 Experimental

3.1 Materials and methods

NMR spectra of bromo derivatives of 1,3-dicarbonyl compounds (Table 4) were recorded on model DPX300 Bruker FT-NMR instruments while all other NMR were recorded on model DPX 200 Bruker FT-NMR. FT-IR spectra were recorded on Perkin Elmer GX-2000 spectrometer. Gas Chromatograms were recorded on Shimadzu GC-14B using SE-30 column. Melting points were recorded on Veego capillary instrument and may be uncorrected. Analytical thin layer chromatography (TLC) was performed on Aluchrosep Silica Gel 60/UV_{254} plate. Purification of some of the reaction products (tribromophenol; 4,6-dibromo-2-chlorophenol; 1-bromo-2-naphthol; 4-bromo-*N*,*N*-dimethylaniline; 1-bromonaphthalene; bromohydrins) was carried out by column chromatography using 100–200 mesh silica gel. All reactions were carried out under ambient conditions with magnetic stirring unless otherwise stated. Unless otherwise stated, yield refers to isolated yield. The purity of all compounds was checked by ^{1}H-NMR, FT-IR, microanalyses (Perkin-Elmer model 2400), melting point and boiling point. Purities of tribromoaniline, tetrabromobisphenol A, *N*-bromosuccinimide and bromobenzene were estimated by HPLC (Shimadzu model with CTO 10A UV-vis detector and Nucleosil C18 column) and also by differential scanning calorimetry (Mettler Toledo Model DSC 822^e Differential Scanning Calorimeter using Star^e software). Reaction calorimetric studies were conducted on an RC1:Mettler make SV01 calorimeter fitted with an 800 ml capacity all glass reactor equipped with a propeller type upflow agitator, jacketed with a controlled temperature circulator, addition funnel, condenser, and the calibration and temperature probes.

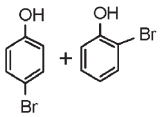
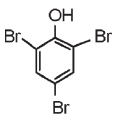
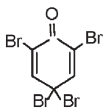
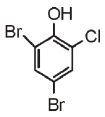
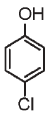
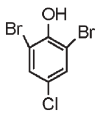
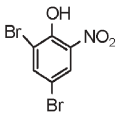
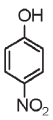
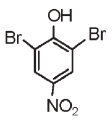
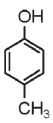
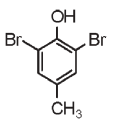
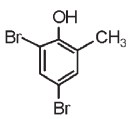
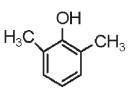
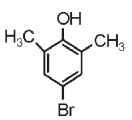
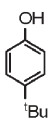
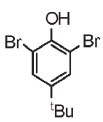
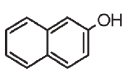
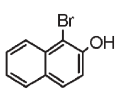
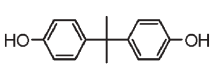
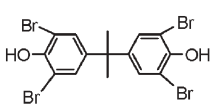
3.2 Preparation of 2 : 1 Br^- : BrO_3^- reagent from alkaline bromine mixture and sodium hypochlorite

62 g (0.83 moles) of sodium hypochlorite was added into 894 mL of alkaline bromine intermediate, containing a total of 262 g (3.26 moles) of dissolved bromine in the form of 4.7 : 1 mole ratio of Br^- : BrO_3^-. The contents were mixed thoroughly and allowed to react for 24 h in a closed 5 L round-bottom flask, to obtain the 2 : 1 Br^- : BrO_3^- reagent having 241.85 g of available bromine. Eqn 2 shows the stoichiometry for conversion of 5 : 1 Br^- : BrO_3^- into 2 : 1 Br^- : BrO_3^-.

3.3 General procedure for the preparation of bromophenols

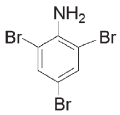
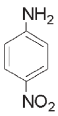
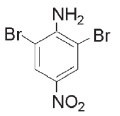
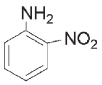
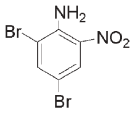
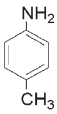
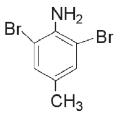
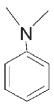
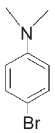
A known quantity of the organic substrate was taken in a single neck 100 mL round-bottom flask containing either water (entries 1–3; Table 1) or dichloromethane in 1 : 10 and 1 : 5 (w/v) substrate to solvent ratio, respectively. To it, an aqueous solution (*ca.* 5 mL water per gram of reagent) containing the stoichiometric equivalent of brominating reagent was added under stirring at 25–40 °C. Then the

Table 1 Polybromination of phenols[a]

Entry	Substrate	No. eq. of Br	Time/h	Product	Yield (%)[b]
1		1	2		91[c]
2		3	2–3		93
3		4	2–3		94
4		2	2–3		90[d]
5		2	2–3		98
6		2	2		98.5
7		2	2		96
8		2	2		99
9		2	2		97.5
10		1	2		97
11		2	2–3		95
12		1	2		86[d]
13		4	5		92[e]

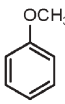
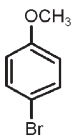
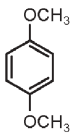
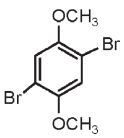
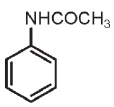
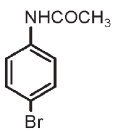
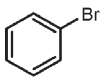
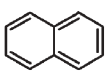
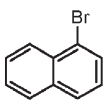
[a] 1–3 are carried out in water medium and other reactions are carried out using CH_2Cl_2 as solvent. [b] Unless indicated otherwise, reported yields are the crude yields after work up. [c] *p/o* ratio was 81 : 19 by GC. [d] Isolated yields after column chromatography. [e] Average yield of 5 batches with recycling of the mother liquor.

Table 2 Bromination of amines[a]

Entry	Substrate	No. eq. Br	Time/h	Product	Yield (%)
1		3	2		96
2		2	2		98.7
3		2	2		98.5
4		2	2		84[a]
5		1	2		85[a]

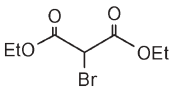
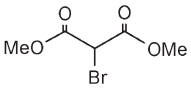
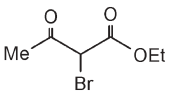
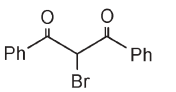
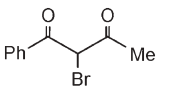
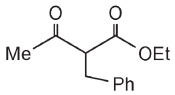
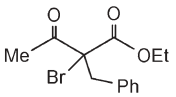
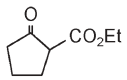
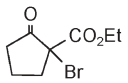
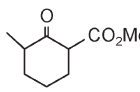
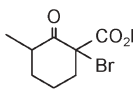
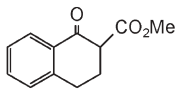
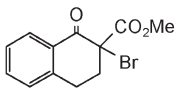
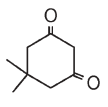
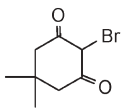
[a] MeOH is used as solvent in entry 1 and CH_2Cl_2 in entries 2–5. [b] Yields after column chromatography.

Table 3 Bromination of other aromatic substrates[a]

Entry	Substrate	Time/h	Product	Yield (%)[b]
1		1.5		97[c]
2[d]		2		96.5[c]
3		1		93
4		2		81.3
5		2.4		36[e]

[a] CH_2Cl_2 is used as solvent in entries 1, 2 and 5, MeOH in entry 3 and excess benzene in entry 4. [b] Isolated yields. [c] Crude yields. [d] Two equivalents of brominating reagent is used. [e] Isolated yield after column chromatography. (Note: selectivity of formation was not quantitatively estimated for crude product mixture.)

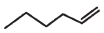
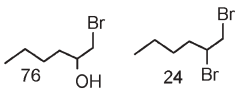
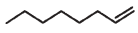
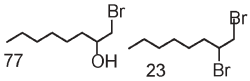
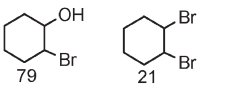
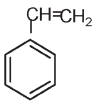
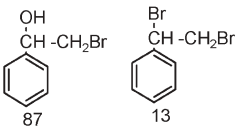
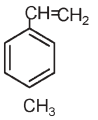
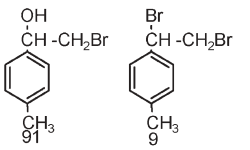
Table 4 Selective monobromination of CH-active compounds

Entry	Substrate	Product	Time/h	Yield (%)[a]	Ref.
1			1.5	65	27
2			1.5	70	28
3			1.2	80	29
4			0.5	90	30
5			3.0	78	29
6			2.5	76	30
7			2.0	83	
8			2.0	80	
9			2.0	91	30
10			0.25	95	30
11			3.5	70	31
12			4.0	60	31
13			3.5	72	32

[a] Isolated yields.

required quantity of 12 N hydrochloric acid solution was added drop-wise to the flask under stirring at room temperature over a period of 30–60 min. After complete addition of the acid solution, the stirring was continued for another 40 to 60 min and the product was extracted with 3 × 25 ml of dichloromethane or diethyl ether. (Note that in the case of entries 2 and 3 of Table 1, the product was washed directly with water and dried.) The combined organic extracts were washed successively with 5% sodium thiosulfate, water and then brine, followed by drying over anhydrous sodium

Table 5 Synthesis of bromohydrins

Entry	Substrate	Time/ min	Product ratio (%)	Total yield (%)[a]
1		30	 76 24	66
2		30	 77 23	85
3		45	 79 21	85
4		45	 87 13	91
5		45	 91 9	90

[a] Isolated yields after column chromatography in dioxane as solvent.

sulfate and evaporation of solvent under reduced pressure. The product was purified wherever required by column chromatography on silica gel. The identity and purity of the products formed were characterized by the analytical techniques mentioned above.

3.4 General procedure for the bromination of anilines

A known quantity of the organic substrate was taken in a single neck 100 mL round-bottom flask containing dichloromethane or methanol in 1 : 5 (w/v) substrate to solvent ratio. To it, an aqueous solution containing the calculated quantity of brominating reagent (BR) was added under stirring at 25–40 °C. Then the required quantity of aqueous hydrochloric acid solution was added drop-wise to the flask under stirring at room temperature over a period of 60 min. (Note: One mole excess acid w.r.t. amine was used to offset the formation of amine salt.) After complete addition of the acid solution, the stirring was continued for another 40 to 60 min and the product was extracted with 3 × 25 ml of either dichloromethane or diethyl ether. The combined organic extracts were washed successively with 5% $NaHCO_3$, water and then brine, followed by drying over anhydrous sodium sulfate and stripping off solvent under reduced pressure. The product was purified wherever required by column chromatography on neutral alumina (active) using the desired % of ethyl acetate and hexane. The identity and purity of the products formed were established by conventional analytical techniques.

3.5 General procedure for bromination of CH acidic compounds

1.5 g of the brominating reagent was added to the dispersion of ethyl acetoacetate (5 mmol) in aqueous methanolic solution (15 ml) at 0 °C. After that ~0.9 N HCl solution (15 ml) was added dropwise over 15 minutes at that temperature and stirred for 1.5 h until completion of the reaction (TLC). The excess bromine was decomposed with aqueous Na_2SO_3 solution. The product was extracted with diethyl ether and washed with water and evaporated in vacuum to leave the crude compound, which was purified by column chromatography over silica gel (*n*-hexane : ether = 95 : 5) to give pure monobromo compound (80%) as a yellow oil.

Analytical data for entry 7, Table 4: Brownish oil; ν_{max}(neat)/cm^{-1} 1722, 1759; δ_H/$CDCl_3$ 1.31 (t, J = 7.2 Hz, 3H), 2.10–2.18 (m, 2H), 2.25–2.52 (m, 3H), 2.70–2.81 (m, 1H), 4.29 (q, J = 7.2 Hz, 2H); δ_C/$CDCl_3$ 13.8, 19.3, 35.2, 38.6, 54.6, 63.0, 166.7, 205.8. (Found: C, 40.57, H, 4.52. $C_8H_{11}O_3Br$ requires C, 40.87; 4.72%).

Analytical data for entry 8, Table 4: Yellow oil; ν_{max}(neat)/cm^{-1} 1725, 1755; δ_H/$CDCl_3$ 1.06 (d, J = 6.3 Hz, 3H), 1.36–1.38 (m,2H), 1.70–1.77 (m, 1H), 1.97–2.13 (m, 2H) 2.48–2.54 (m, 1H) 2.98–3.04 (m, 1H), 3.78 (s, 3H); δ_C/$CDCl_3$ 15.2, 24.2, 35.7, 42.1, 44.2, 53.5, 68.2, 168.2, 199.2. (Found: C, 43.19; H, 5.11.$C_9H_{13}O_3Br$ requires C, 43.39; H, 5.26%).

3.6 General procedure for preparation of bromohydrins

1.0 g (12.2 mmol) of cyclohexene in 10 mL of dioxane was placed in a 100 mL round-bottom flask. Into it was added 2.436 g (12.18 mmol active Br) of brominating reagent in 30 mL of water. The mixture was stirred at room temperature with controlled addition of dilute sulfuric acid (12.2 mmol) over 15 minutes, stirred for an additional 30 minutes and extracted with 75 mL (25 mL × 3) of diethylether. The combined organic extract was washed with dilute sodium thiosulfate (5%), water, and brine, and dried over anhydrous sodium sulfate. Evaporation of ether left the crude product which was purified by column chromatography over silica gel (hexane–ethyl acetate 9 : 1) to get the pure *trans* 2-bromocyclohexanol as colorless liquid (1.42 g, 7.94 mmol) in 65% yield and 1,2-dibromocyclohexane (0.25 g, 1.033 mmol) in 17% yield. Spectroscopic data (^{1}H, ^{13}C NMR and IR) of the above products are in good agreement with those of authentic samples.

3.7 Special procedures

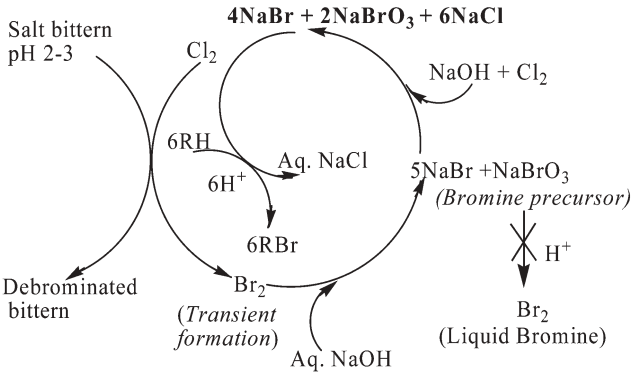
Tetrabromobisphenol A (TBBP-A) from bisphenol-A (BP-A) (entry 13, Table 1). 0.50 kg (2.193 mol) of BP-A, 1.5 L dichloromethane (DCM), 1.752 kg brominating reagent (containing 8.772 mol available Br) and 3.1 L water were placed in a 10 L glass reactor. To this reaction mixture, 0.912 L (8.86 mol) of 12 N HCl was added drop-wise over a period of 12 h under stirring at R.T. After the complete addition of acid, stirring was continued for further 30 min. 0.80 kg (1.471 mol; 67% yield) of TBBP-A (m.p.180–184 °C) was obtained after filtering and drying at 100 °C for 3 h. The organic layer (0.85 L) was separated from the aqueous layer. It was recycled in the subsequent 0.50 kg batch of BP-A subjected to bromination in analogous manner. 1.07 kg (1.97 mole) of TBBP-A (m.p. 181–184 °C) was obtained. The overall isolated yield from the two batches was 78.5% and the organic layer, which also contained

TBBP-A and intermediates, was once again recycled to continue the process. In this manner, yields in excess of 92% could be realized. The purity of TBBP-A thus obtained was estimated to be >98% by HPLC and DSC.

4-Bromoacetanilide (entry 3, Table 3). The title compound was prepared according to the general procedure described in 3.3 above using acetanilide (1.0 g, 7.407 mmol) in 10 mL methanol. 1.480 g of brominating reagent in 20 mL water was added into the above solution, followed by dropwise addition of 20 ml of aqueous 0.923 N hydrochloric acid (17.964 mmol). White amorphous solid separated out, which was filtered and washed with water until it became free from acid. The product was dried at 100 °C to yield 1.4742 g of 4-bromoacetanilide in 93% yield.

Preparation of bromobenzene (entry 4, Table 3). A 2 : 1 mixture of NaBr : $NaBrO_3$ constituted from 10 g (0.097 mol) of NaBr and 7.33 g (0.485 mol) of $NaBrO_3$ was dissolved in 75 mL water and placed in a 250 mL three neck round-bottom flask fitted with a water condenser. 0.2 g of sodium lauryl sulfate (SLS) was also added. Excess benzene (57 mL, 0.64 mol) was added next and the flask slowly heated to 70–75 °C under stirring. 25 mL of 7.3 N HCl (0.18 mol) was added to the hot reaction mixture over 10 h. The hot reaction mixture was stirred for another 30 h and then cooled to room temperature. The organic and aqueous layers were separated. The aqueous layer was extracted at least three times with minimum quantity of ether. The extracts were combined with the organic layer, washed successively with water and brine and dried over anhydrous sodium sulfate. Solvent was stripped at reduced pressure and the resultant liquid was vacuum distilled to yield 18.6 g (81.3% yield w.r.t. to brominating reagent) of bromobenzene. The purity was estimated to be 95% by HPLC (*ca.* 2% of benzene was present in the product due to imperfect distillation). A similar result was obtained at 100 g scale using the 2 : 1 brominating reagent prepared from the alkaline bromine intermediate as described above.

***N*-Bromosuccinimide (NBS).** A 2 : 1 mixture of NaBr : $NaBrO_3$ constituted from 13.87 g (0.135 mol) of NaBr and 10.17 g (0.067 mol) of $NaBrO_3$ was dissolved in 60 mL water and placed in 250 mL round-bottom flask. 20.0 g (0.202 mol) of succinimide was added and the contents stirred at 10–15 °C for 5–10 min to dissolve the solids. Then 12 mL of 18.0 N H_2SO_4 was added slowly under stirring over 2 h. The white solid formed was filtered, washed with cold water, and dried in an oven at 100 °C for 2 h to yield 28.0 g (78%) of NBS. A similar result was obtained at 100 g scale using the 2 : 1 brominating reagent prepared from the alkaline bromine intermediate as described above. The isolated yield was 80% and the purity was estimated to be *ca.* 92% by iodometry method. Analytical data: ^{1}H-NMR ($CDCl_3$-200 MHz) (δ) 2.97(4H, s). IR: ν_{max} (KBr) 3184, 3057, 2934, 2649, 2541, 1696, 1417, 1309, 1199, 919, 638, 581, 425 cm^{-1}. CHN: Found C, 28.05%; H, 2.47; N, 7.78%; calcd C, 29.63%; H, 1.98%; N, 8.64%. Melting point: observed 180–181 °C (reported 180–183°C).



Scheme 1

4 Conclusion

We have exploited the redox reaction between bromide and bromate ions in the presence of acid to develop an eco-friendly brominating reagent directly from the 5 : 1 Br^- : BrO_3^- alkaline intermediate of bromine plants that are based on the "cold process" of manufacture. By adjusting the Br^- : BrO_3^- mole ratio to 2 : 1 through oxidation with Cl_2–NaOH, BrOH—instead of Br_2—is obtained on acidification. This redox process may be carried out in the presence of organic substrates to effect bromination. Scheme 1 shows the eco-friendly nature of the process all the way from cradle to grave.

BrOH—more specifically $BrOH_2^+$ which forms in the presence of excess acid[35]—is not only more active than liquid bromine, but it also results in high bromine atom efficiencies in most of the reactions studied. NaCl present as an inert salt in the reagent has no adverse effect on the reaction, whereas significant gains are realized in terms of simplicity and cost-effectiveness of preparation of the reagent. Since bromine manufacturers themselves can produce the reagent from the precursor—rather than from liquid bromine—the reagent has the potential to be eco-friendly across the entire life cycle. Besides aromatic bromination reactions, CH-acidic compounds could be monobrominated selectively and olefins could be converted into the corresponding bromohydrins in moderately good yields and selectivity. Another application is the clean synthesis of other brominating reagents such as *N*-bromosuccinimide and 2,4,4,6-tetrabromo-2,5-cyclohexadienone, which extends the scope of application considerably for selective bromination as well as for bromination of water-sensitive substrates. It is hoped that the present protocol will also make it simple to recycle the spent reagents. An important extension of the present work would be the conversion of bromide-containing waste streams—*e.g.*, during formation of trimethoxyaniline from tribromoaniline—into 2 : 1 bromide–bromate mixture which can be reutilised for synthesising the bromo intermediate once again with high atom efficiency.

Although some of the reactions were conducted with only water as solvent, we would like to avoid the use of organic solvents—especially that of chlorinated solvents—to the maximum extent possible. Alternatively, the processes can be made eco-friendly by recycling the organic phase as demonstrated in the preparation of TBBP-A. When the recycling option is feasible, less volatile solvents can be used, *e.g.*, use of dichloroethane instead of methylene chloride. The process can

be made still more eco-friendly by regenerating HCl and NaOH from the aqueous effluent through electrodialysis with bipolar membranes.

Finally, efforts are underway to explore other possible applications of the present reagent going beyond bromination.

Acknowledgements

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