Learn Chemistry

Business Skills and Commercial Awareness for Chemists

Waste-stream Management Scenario

Developed by the University of York and University of Warwick

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Waste-stream management scenario

Your company makes a range of organic intermediates based on substituted aromatics, serving the pharmaceutical, paint, agrochemical, and other sectors (Figure 1). A key product range is optical brightening agents (OBAs) for paper, detergent and textiles.

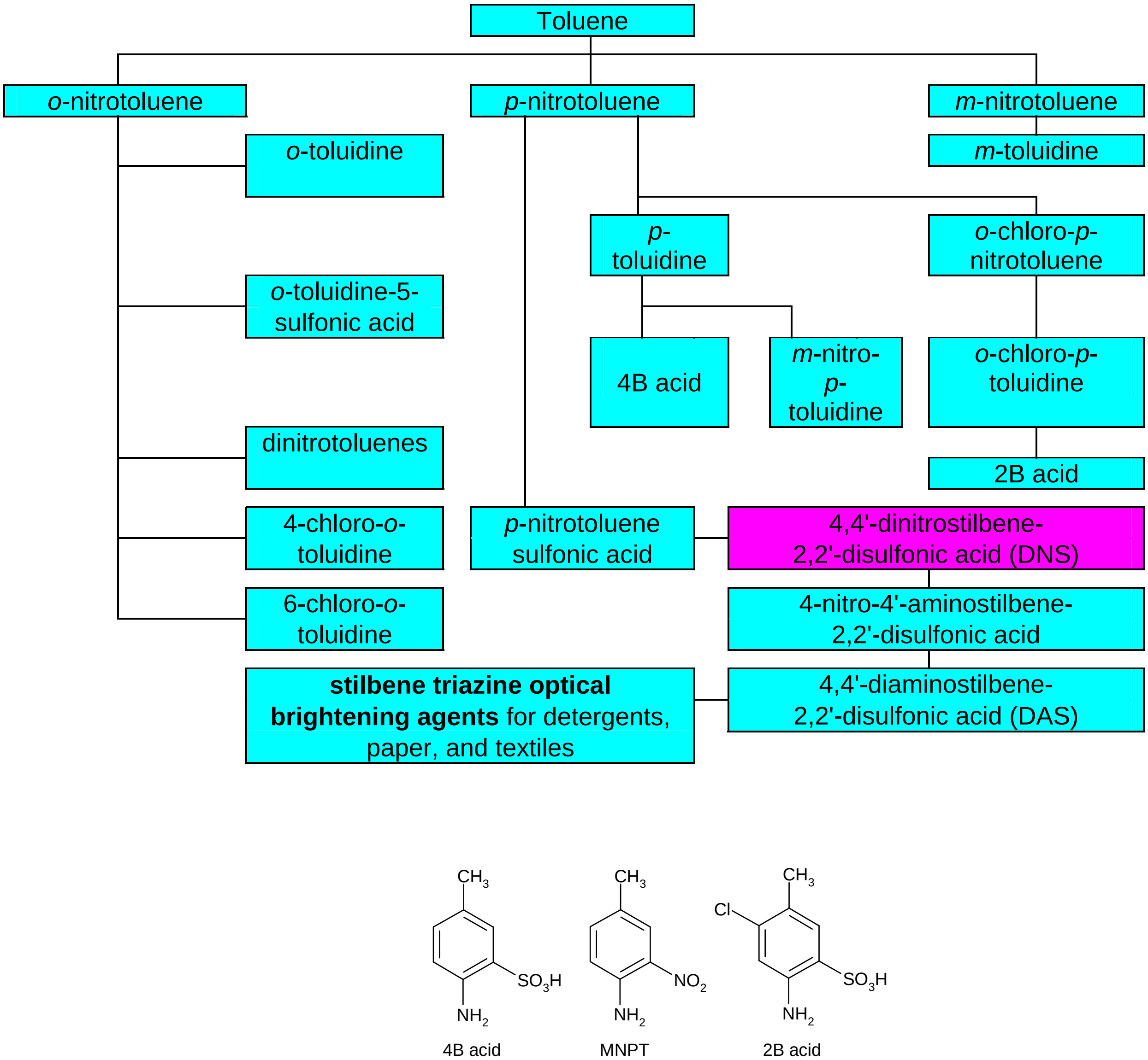

Figure 1 Company Product Range

You currently sell OBAs for £3000 per tonne, with a cost of manufacture of £2500 per tonne. The usage of DNS into OBA is 0.49 tonne per tonne and the cost of manufacture of DNS is currently £1600 per tonne.

In addition to OBAs, other chemical intermediates are produced from toluene (Figure 1), which is bought in bulk from a major petrochemical source. Approximately 40,000 tonnes of toluene are processed per year and the capacity of the DNS production plant is approximately 5000 tonnes per year. There are markets for DNS and DAS as stand alone products in addition to the internal conversion to OBA's.

For some time, the manufacture of DNS (Figure 2) has created a particularly problematic waste-stream and the situation has become critical due to a notification of new discharge consents being imposed on your local treatment works and described separately.

The production of OBAs begins with *para*-nitrotoluenesulfonic acid which is manufactured on-site from toluene.

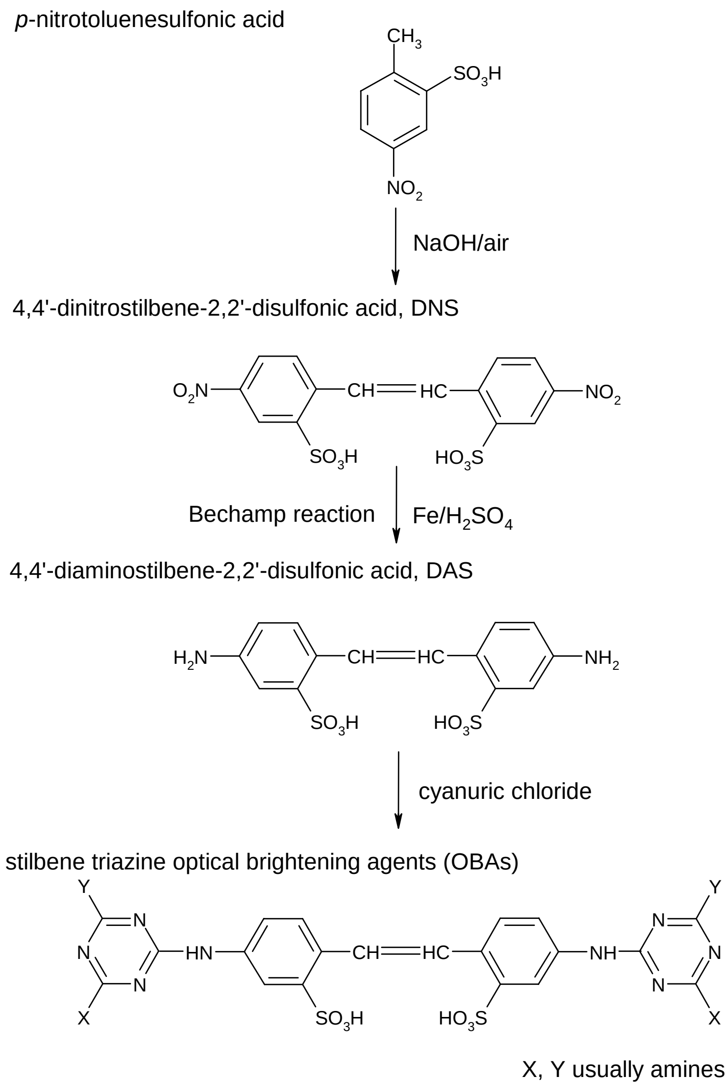

Figure 2 OBA Production

DNS process outline

To a 10,000 gallon stirred, mild steel vessel is charged water and an aqueous solution of *p*-nitrotoluene sulfonic acid to give a concentration of about 10%. To this is added caustic soda solution and a rapid flow of air below the surface of the liquid is initiated. The batch is slowly heated to the reaction temperature of 70°C and is held at this until analysis of a sample shows that the reaction is complete. After transferring to a crystallisation vessel, the pH of the mixture is adjusted to 9 with sulfuric acid and sufficient salt is added so that a specific gravity of 1.1 is achieved. After subsequent cooling to 25°C, the product is isolated on a centrifuge and water washed. The product is discharged to semi-bulk containers for further processing and the

aqueous effluent is pumped to a storage tank and from there is fed to the works effluent system.
Output of DNS averages about 9 tonnes per day. The production cost of DNS is currently estimated at £1600 per tonne

Current effluent treatment protocol

DNS and other waste streams are biologically pre-treated on-site before discharge to the local waste water treatment plant where further biological, chemical and filtration treatment takes place prior to discharge to river. On-site biological treatment of the DNS waste stream takes places in a dedicated bio-tower using bacteria specially bred to survive in the highly saline conditions of this effluent. Standard bio-tower treatment suffices for other waste streams. The annual cost of feeding the total works effluent to the local sewage works is of the order of £1M.

The problematic DNS waste stream is characterised by:

- black-looking aqueous liquor containing inorganic salts and highly soluble organic compounds, characteristically Abs.(450 nm)=2.40; Abs.(550 nm)=0.75 (Abs. measured in absorbance units in a 10 mm cell after pre-filtration)
- COD: *ca*. 20,000 ppm
- BOD: *ca*. 400 ppm
- sodium chloride content: 4-5 %
- sodium sulphate: 6-7 %
- soluble organics: *ca*. 2.5 %
- specific gravity *ca*. 1.1
- 40,000 gallons per day

Pre-treatment on-site currently reduces the BOD by *ca*. 90 % just meeting the discharge consent of 9 kg/day imposed by the local waste water treatment works. The COD and colour of the effluent are only slightly reduced by the pre-treatment process.

Another significantly problematic waste stream (which also receives pre-treatment) results from the production of *meta*-nitro-*para*-toluidine (MNPT):

- medium-colour: Abs.(450 nm)=1.08; Abs.(550 nm)=0.40
- COD: *ca*. 8,000 ppm
- BOD: *ca*. 300 ppm
- sodium sulphate: 3 %
- soluble organics: *ca*. 1 %
- specific gravity *ca*. 1.05
- 35,000 gallons per day

The remaining process and cooling water from the site is discharged directly to the waste water treatment plant:

- essentially zero colour
- COD: *ca*. 40 ppm
- BOD: *ca*. 15 ppm
- soluble organics: *ca*. 0.1 %
- specific gravity *ca*. 1.01
- 400,000 gallons per day

Task

Your task is to advise the company on how to respond to the new discharge regime and reports have been commissioned into three technological pre-treatments that may be able to solve the immediate problem with your company waste-streams. These are reverse osmosis, evaporation/incineration, and oxidation technologies. You should consider:

- the technical case i.e. which of the proposed technologies would allow the *status quo* to be maintained and current site production activities to continue;
- the total cost of implementing any satisfactory remedial technologies;
- alternative strategies to circumvent the impending effluent discharge problem that may avoid the need for, or supplement, 'end of pipe' technology solutions;
- making a forecast for growth of the OBA market over the next 5 years, explaining your assumptions;
- making an analysis of the OBA business environment by the STEEP model;
- making an analysis of the competitive environment using Porter's Five Forces Model;
- coming up with **two strategies** for taking the company forward, which must include solving the effluent issue;
- presenting discounted cash flow (DCF) analyses for your **two** scenarios.

Planning a future for your company may include borrowing finance to implement your chosen effluent reduction technology, hence maintaining the *status quo* and satisfying the Environmental Agency effluent levels. You may also consider taking a wider view of the effluent issue and propose scenarios involving the whole site or the immediate locality (which is a highly industrialised urban location), or you may consider the global OBA market position. Various levels of investment may be required to support your plans and you also need to convince shareholders of the wisdom of your proposals. Your recommendations should be presented in the form of a business plan, including a *ca*. 150 word executive summary.

Assessment

If your report is to be assessed as part of your coursework, please consult your tutors for the assessment criteria.

Supporting information documents

New discharge consents & treatment charges
Reverse osmosis report
Evaporation/incineration report
Oxidation report
OBA market info

Waste Water Treatment Works: Notice of new customer charges

We draw your attention to the Environment Agency's imposition of new discharge consents for the water we currently release to river (attached). This will have two immediate consequences for you from the date of implementation: there will be a maximum level of water contamination that we will be able to treat, and our charges will be revised to take account of the additional processing required for effluent approaching our maximum permitted contamination level. We have particular concern about the level of colour and COD of the effluent from your site.

Our charging formula under the Urban Waste Water Treatment Directive will now be:

Total charge : $\mathbf{R} + \mathbf{P} + \frac{(Ot)}{(Os)} \mathbf{B}$

Ot - the Chemical Oxygen Demand of your effluent
Os - the Chemical Oxygen Demand of the total discharge effluent to waste water treatment works, currently quoted at 200 mg l^{-1}.

Treatment charges:

R - reception charge	<50,000 m^3/year	25.14 pence/m^3
	>50,000 m^3/year <250,000 m^3/year	15.69 pence/m^3
	>250,000 m^3/year	11.97 pence/m^3
P - primary treatment charge		26.91 pence/m^3
B - biological treatment charge		27.18 pence/m^3

The COD figure will be an average value based on daily determinations. ***We will not accept waste with a COD in excess of 2100 ppm***.

Colour

Since your effluent at present falls *just* within *existing* colour discharge consents, after our treatment, you can assume that a similar percentage diminution will continue to be achieved due to our processing. This means that you can continue to exceed the new river discharge consents but only by the small amount removed by our treatment. ***We will not accept waste exceeding this colour level***.

Environment Agency: Notice of intent

Commercial operators with consent to discharge to designated water courses are advised of new water quality consents with effect from 4 March next year.

	Before 4 March	***After 4 March***
BOD:	35 mg l^{-1}	20 mg l^{-1}
COD:	-	125 mg l^{-1}
TSS:	30 mg l^{-1}	25 mg l^{-1}
Colour: Absorbance[a] at:		
400 nm	0.30	0.060
450 nm	0.26	0.040
500 nm	0.18	0.035
550 nm	0.15	0.025
600 nm	0.15	0.025
650 nm	0.12	0.015

([a]Absorbance measured in absorbance units in a 10 mm cell after pre-filtration through 0.45 μm membrane)

Report #3 **Date:** Jan.

Summary report of OsmoTech

We report findings (Table 1) relating to reverse osmosis treatment of the 'DNS' waste stream. Our trial results relate to a 200 ml sample of DNS effluent, nanofiltration being performed through a polyamide filter. Permeate and concentrate (retentate) analyses were performed at the initial point, the mid-point, and the end point of filtration.

Table 1 RO treatment data, DNS waste-stream

Conc. factor initial vol/vol	**Concentrate**				**Permeate**			
	Colour (450 nm)	**COD** (mg/l)	**sodium sulphate** (g/l)	**sodium chloride** (g/l)	**Colour** (450 nm)	**COD** (mg/l)	**sodium sulphate** (g/l)	**sodium chloride** (g/l)
1	2.45	20408	38	43	0.09	3130	2	31
2	3.45	26250	42	21	0.28	6530	3	28
5.9	9.25	54170	117	10	1.20	10210	20	24
				Composite	0.15	4580	4	27

Equipment costs

We do not currently supply equipment of sufficient capacity for your current rate of production of DNS effluent. The largest machine we offer to treat your effluent, based on a retentate to permeate ratio of 1:6, can handle about 70t/day. We would supply, fit, and commission such equipment at a cost of £495k per machine. We advise you of the additional cost of suitable membrane modules at a further cost of £3800. We cannot accurately predict the required replacement rate for these modules but it is likely to be needed on a regular basis necessitating appreciable downtime.

Process operation

Our engineers anticipate problems with high sodium sulphate levels in the retentate with potential for catastrophic blockage of the membrane. It may be desirable to 'lime' for sulphate removal which will add an additional waste stream corresponding to precipitated sodium sulphate.

Comments

Expect to pay *ca*. £100/te to dispose of the retentate from this process.

Report #4 **Date:** Feb.

Summary report of CleanaChem

We are pleased to report findings (Table 1) relating to evaporation/incineration treatment of the 'DNS' waste stream. We would propose to evaporate 73% by volume of the feed, producing a 5% by wt slurry of Na_2SO_4/NaCl in mother liquor which can be handled in rubber-lined equipment.

Table 1 Evaporation data, DNS waste stream

STREAM	Na_2SO_4 Wt%	NaCl Wt%	Organics Wt%	H_2O Wt%	TOTAL kg/hr
Feed	6.37	4.55	2.09	86.99	
Crystal	92.8	5.7	1.5	-	
Mother liquor	17.2	15.2	7.2	60.1	
Misc. water addn.				100	251
Total evap.				100	5955

Process description

A double-effect evaporation/crystallisation plant is proposed. Feed liquor is fed via a pre-heater to the 2nd effect body. The liquor is partially concentrated to an unsaturated condition in the 2nd effect falling film evaporator and passes to the 1st effect forced circulation evaporative crystalliser.

Mixed NaCl/Na_2SO_4 is crystallised in the 2nd effect body: a slurry stream is removed from this body for disposal by incineration.

Steam at 10 psig/min is fed to the 1st effect shell: vapour from the 1st effect is used as heating steam in the 2nd effect shell. Vapour from the 2nd effect is condensed in a surface condenser. Vacuum is maintained on the plant by a liquid ring vacuum pump. Steam condensate is returned at 94 ^{o}C. Process condensate is pumped to site effluent treatment via the feed preheater.

Slurry to the incinerator is burnt to destroy the organic matter. Inorganic salts are collected by a bag filter prior to discharge of the flue gases to atmosphere. As an option, a triple effect plant could be used, reducing steam requirements at the expense of extra capital cost.

Equipment and utilities

	Double-effect plant	***Triple-effect plant***
Steam (at 10 psig/min)	3900 kg/h	2900 kg/h
Cooling water (25 ^{o}C max.)	110 m^3/h	110 m^3/h
Power	75 kW approx.	80 kW approx.
Incinerator fuel	2,775,000 kcal/h	2,775,000 kcal/h
Plant cost*	£1,075,000	£1,175,000

(*inclusive of delivery, offload, and installation; exclusive of utility connections, feed pump, solids handling from bag filter)

Incineration

We have received a quote of approximately £3M to establish a suitable incinerator at your site. We can also source contract incineration on your behalf, currently £200/tonne for the type of slurry produced by the evaporation process.

Comments

Water: £0.50/m^3
Steam (at 10 psi): £5.00/tonne
Fuel: (natural gas) 1.2p/kWh

Report #5 — **Date:** Aug.

Summary report of Cleanox

We report findings relating to oxidation treatment of the 'DNS' waste stream (Table 1).

We have trialled two oxidation processes which have proved successful with similar waste streams in the past. The results are presented alongside estimates for equipment costs and utilities/consumables involved. We have scaled our trial results to reflect estimated utilities/consumables per cu. metre of effluent treated.

Table 1 Oxidation treatment data, DNS waste stream

	WetOx	**LowOx**
Plant capital, £M	3.2	*
Operating pressure, bar	50	20
Temperature, ^{o}C	250	200
COD reduction, %	97	96
BOD reduction, %	-5	-5
Colour reduction (580 nm), %	96-98	95
Electricity usage, kWh/m^3	20	18
Oxygen use, kg/m^3	11	11
Cooling water, m^3/m^3	8	6

* We currently licence our LowOx technology through OBC and offer a full-service treatment cost based on us installing, maintaining, and operating the effluent treatment facility at your site. You would pay a fixed all-inclusive charge for effluent treatment which we hereby quote at £16/tonne. EborChemCo Industries would retain responsibility for the final disposal of treated effluent. Alternatively, we can arrange direct and outright purchase of the process equipment. As a guide, we have recently commissioned a large facility, capable of handling 1000 m^3/day, at a capital outlay of £10M. The operator then has responsibility for running, maintaining, and supplying utilities to the facility.

The World Market

The main manufacturers of OBAs are given in Table 1, together with their market share.

Table 1: Optical brightening agent (OBA) global market share by company

Manufacturer	Market Share (tonne per year)
Ciba	8000
Sigma	5000
EborChemCo	2500
Bayer	1000
Makhteshim	400
Others	4000
Total =	20900

The total world market for OBAs has been growing over the last ten years as shown in Table 2.

Table 2: Optical brightening agent (OBA) world market by year

Year	Total World Market of OBA's (tonne per year)
Current	20,900
Current minus 1	20,500
minus 2	17,000
minus 3	15,000
minus 4	12,000
minus 5	11,800
minus 6	10,000
minus 7	9,600
minus 8	9,000
minus 9	8,800