The Titan Project

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The Titan Project

Titan Industries have just purchased a titanium dioxide plant in Midshire.

As the management team, your mission is to recommend a five-year plan for the site.

Any imminent expenditure plans need to be fully justified.

What you need to do

Consider

- Why there is a TiO_2 plant here
- The advantages / disadvantages of SP and CP
- What the various options are for the site are
- A strategy for the next 5 years

Present your recommendations to the board

The Titan Project

SCIENTIFIC SKILLS

- industrial chemistry
- the pigment industry
- environmental & safety issues
- economics
- political and social context
- analytical methods
- statistics

TRANSFERABLE SKILLS

- working with others
- communication
- decision making
- analytical/critical thinking
- independent learning
- time management

What you need to do

Consider

- Why there is a TiO_2 plant here
- The advantages / disadvantages of SP and CP
- What the various options are for the site are
- A strategy for the next 5 years

Present your recommendations to the board

The Pigment Industry

You are the existing management team empowered by Titan Industries (TI) to make recommendations on the future of the site. The following report has been prepared is considered highly relevant to your project.

Titan Industries is one of the top 5 titanium dioxide producers in the world. TI has just bought the complete TiO_2 businesses of a smaller, but significant, producer in a multi-million pound deal. The acquisition was part of an ongoing long-term strategy to concentrate on the core business of bulk TiO_2 production and has given TI an increased market share.

The aim of the company is to increase output and efficiency at specific sites to capture a larger market share when demand increases. This will be financed by the sale of non-core subsidiary companies over the next few years. However, at this time the company has a cash flow problem. Most of the sites acquired are in the Asia/Pacific region although there are also a small number of European sites.

Raw Materials

The titanium dioxide industry uses the following minerals as the initial raw material - the average content of TiO_2 is given in brackets; **ilmenite** (35-65%), **rutile** (90-98%), **synthetic rutile** (85-96%), **titanium slag** (70-85%).

The Sulfate Process (or 'wet process'):

The older method of industrial TiO_2 production and requires the cheaper ilmenite or titanium slag as a starting material. Key steps in the process are:

1. **Benefication** (Pre-treatment)**:** This involves milling, screening and drying of raw materials followed by removal of any metallic iron, using magnets.

2. **Acid Digestion:** The prepared ore is then digested in sulfuric acid. This process takes around 12 hours and involves the addition of concentrated sulfuric acid to the ore in the presence of water. The result is a solution containing titanium and iron species.

$$FeTiO_3 + 2\,H_2SO_4 \rightarrow TiOSO_4 + FeSO_4 + 2\,H_2O$$

3. **Washing:** The 'cake' produced by the acid digestion is then washed with warm water (or dilute acid) to remove as much iron sulfate as possible.

4. **Hydrolysis:** Hydrolysis of the resulting Ti species gives a hydrated form of titanium dioxide and free sulfuric acid:

$$TiSO_4 + (n+1)\,H_2O \rightarrow TiO_2.nH_2O + H_2SO_4$$

The hydrolysed gel must be removed and washed quickly to prevent dissolution in the liberated sulfuric acid. Seeds of the required crystal structure are added.

5. **Washing, Doping:** After washing to remove the majority of the sulfuric acid, small amounts of any required additives are added.

6. **Calcination:** The hydrated gel is heated in rotary kilns in the presence of excess air. Careful temperature control is essential.
   - For anatase production, a final temperature of 800 - 850^{o}C is necessary (the hydrated gel having been seeded with anatase crystals).
   - For rutile production a higher final temperature of 900 - 930^{o}C is required (the hydrated gel having been seeded with rutile crystals).

7. **Milling:** once cool, the titanium dioxide produced can be milled and surface treated in order to obtain the desired refractive properties from the pigment.

The Chloride Process (or 'dry process')

This process was developed in 1957 as an alternative large-scale route to titanium dioxide and requires rutile (preferably with a TiO_2 content of around 95%) as a starting material. Key steps in the process are:

1. **Pre-treatment of the ore:** The crude ore is finely ground and thoroughly dried.

2. **Formation of $TiCl_4$:** The rutile is heated to 800 to 1200^{o}C in a stream of chlorine gas and in the presence of coke.

$$TiO_2 + 2\,Cl_2 + C \rightarrow TiCl_4 + CO_2$$

3. **Reaction with oxygen:** The pure titanium tetrachloride is pre-heated and reacted with oxygen at 900 - 1400^{o}C to give TiO_2. The chlorine produced can be recycled. 2).

$$TiCl_4 + O_2 \rightarrow TiO_2 + 2\,Cl_2$$

The product produced is rutile. The quality of the product is affected by factors such as temperature, stoichiometry of reaction with oxygen, method of mixing.

4. **Milling:** The product is ground to the particle size required by the end user of the pigment and, where necessary, treated with surface agents.

Sulfate vs. Chloride Process

Since its introduction in 1950's, the *Chloride Process* (CP) has steadily grown in importance. In the early 1990's, CP overtook the *Sulfate Process* (SP) as the dominant source of commercial TiO_2. In the 1980's the proportion of Sulfate Process produced TiO_2 was about 65% and today has fallen to 35%. This trend is expected to continue.

- The CP is a continuous process whereas the SP is a batch process.
- The SP can produce both rutile and anatase forms of TiO_2, whilst the CP is limited to rutile production. This can be a major benefit as no contamination of high quality rutile with anatase occurs.
- The waste produced during the SP is the main problem with this method and can amount to 3-4 tonnes of iron sulfates and 8 tonnes of dilute acid per tonne of TiO_2 produced. However, solid waste can be useful and saleable.
    - Iron salts sold to the water supply industry for use in the manufacture of water purifying products. Also used extensively as soil additives.
    - Gypsum is sold as soil fertilisers for farming and used in the manufacture of building materials such as plasterboard etc.
    - Carbon dioxide is supplied to commercial greenhouses to promote plant growth and in liquid form to breweries and soft drink manufacturers.
    - Sulfuric acid can be reclaimed and the remains recycled.
- The CP is seen by many as the least environmentally damaging and was developed partly because of the huge amounts of waste produced during the SP. However some problems are presented, including the controlled handling of large amounts of $TICl_4$ and use of potentially hazardous Cl_2.
- Low capital investment is required to set up a SP plant and begin production. CP plants are considerably more expensive to set up. Running costs are also significantly higher for the CP, due to power demand and the higher cost and lower availability of the raw materials although overall efficiency is higher due to the huge production capabilities of a modern CP plant.
- The CP *must* be used for preparation of TiO_2 with a final destination in vehicle top coats and PVC. Together these uses represent about 10% of the world titanium dioxide demand. On the other hand, the SP *must* be used for production of high performance anatase, used in high quality paper and ceramics.

Questions

Titanium Dioxide

1. What is the oxidation state of titanium in titanium dioxide and can it be further oxidised?

2. Without seeing a sample, why would you expect it to be colourless?

Pigments

(You will find the *Kirk Othmer Encyclopaedia of Chemical Technology* or something similar useful as a starting reference.)

3. Discuss briefly the characteristics desirable in a good pigment.

4. Make a short list stating the specific advantages and disadvantages of both rutile and anatase pigments as a consequence of their distinct properties, explaining briefly how these different properties affect their end uses.

5. If rutile appears slightly yellow in colour, what region of visible light does it absorb? Why is the absorption of UV radiation a problem in the use of TiO_2 pigments?

The Titanium Dioxide Industry

6. What is meant by a 'green field development'?

7. The two industrial methods of preparing titanium dioxide are the *Sulfate Process* and the *Chloride Process.* For **each** of these processes give a list (with brief explanations) of its advantages and disadvantages.

8. List few reasons why it is not usually desirable to run an industry at full capacity (100% production rate) for extended periods.

The Future of the Site

Your mission is to assess the site, weigh up the possible options and recommend the best plan for the future. Due to the current financial situation, any imminent expenditure plans must be well argued and fully justified. It is the aim of Titan Industries to be the number one European producer of titanium dioxide, maximise profits and utilise capacity to the full.

The map shows Titan Industries newly acquired site in Midshire and is their only UK operation. They are looking for a way of breaking into the European (particularly UK) market. Until now TI has been involved almost exclusively in Chloride Process production plants (regarding the Sulfate Process as yesterday's technology), but this site contains one of two Sulfate Process plants acquired in Europe.

The Site

The site consists of a large area land next to the River Coley east of the town of Beauport in west Midshire. This includes a small dock facility, plenty of room for future development and building (only a quarter of the land has been developed). The operational Sulfate Process plant is currently profitable. Although it is old and does require some refurbishment and updating (particularly to conform new environmental legislation.)

The majority of the waste products are currently being pumped out into the estuary with some of the solid waste going to landfill. A competitor, with money available for expansion and development, has expressed interest in the site publicly (and made a considerable offer), promising hundreds of new jobs for the local town and thus swaying public opinion against Titan Industries. The position of the site allows easy import/export of bulk materials to both the US and Europe and is well connected by road and rail.

The Market

Analysts predict a steady upswing in the TiO_2 industry over the next 15 years, particularly in the Asia - Pacific region where your company is now a dominant force. Experts also predict increased competition in the European sector. Careful forward planning is essential, as all companies will be looking for ways of increasing output over the next decade to stake a claim on the predicted demand increases.

Local Industry

There are numerous interactions with local industries, in addition to the wider issues, that could have a bearing on your decisions.

The Town

Originally built around the fishing docks which was the major employer. The fishing industry has declined massively, particularly over the last 20 years and thus unemployment is particularly high. The local MP is coming up for election and very keen to reduce the unemployment figures and brings some development to the area. Titan Industries is US based and is new to the UK and is currently viewed with much suspicion by the local people of Beauport. The old owner of the site was well established in the community and the take-over has stirred up much ill feeling and bad press, locally and nationally, about your company. It is essential that you make every effort to turn this around and appear as considerate of local needs as possible.

Nature Reserve

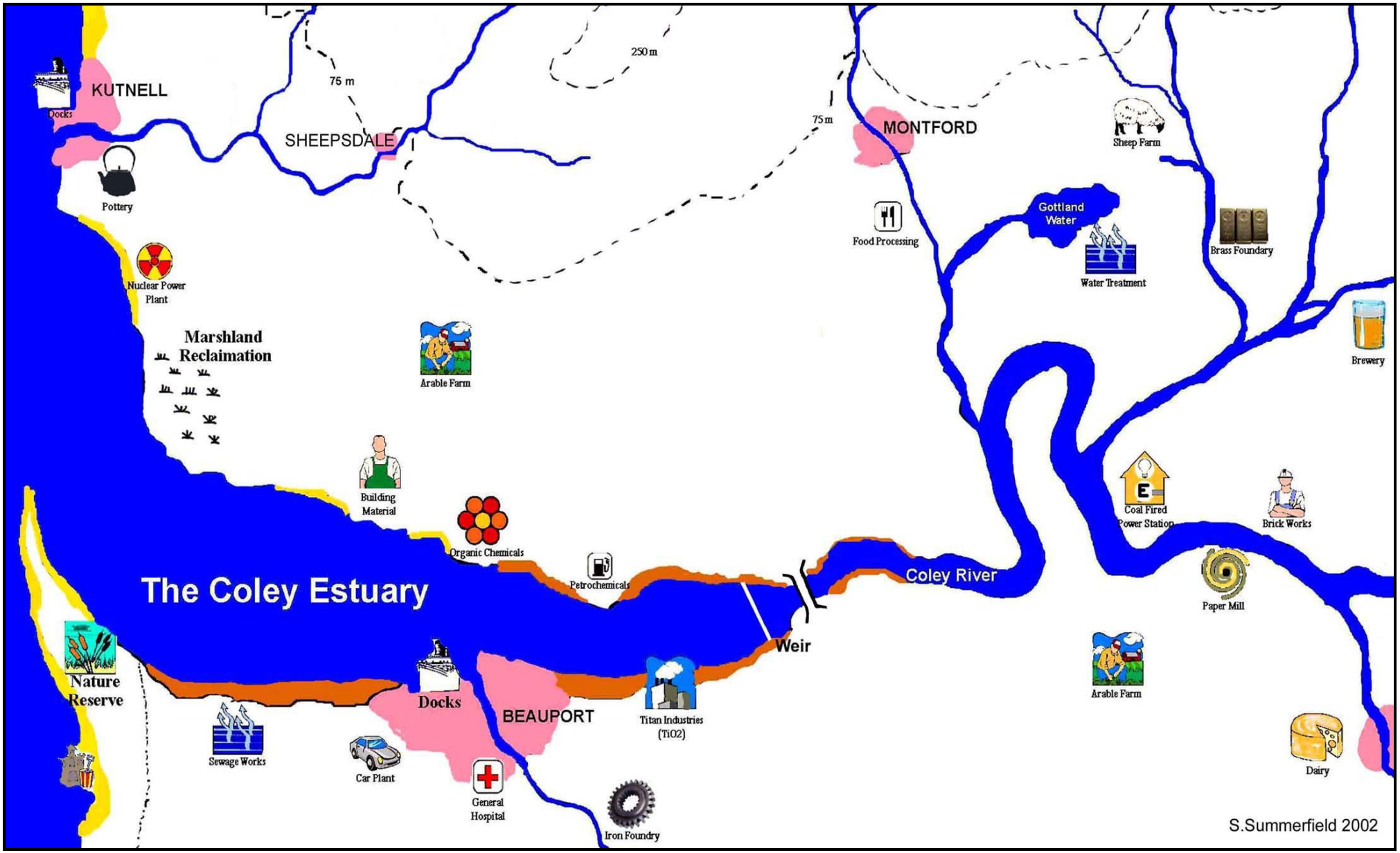
This is a relatively new development due to the discovery of a population of rare toads around the sand dunes. Many protected species now live on the dunes, marshes and woods of the reserve. The area is becoming a popular tourist spot and is increasingly providing vital employment for the local area. Many new businesses have also appeared throughout the town to cater for the increasing number of visitors (including regular school coaches) now passing through. There is talk of further tourist and leisure related developments in the town and surrounding area.

Your Mission

- **List reasons why the site is a good location for a TiO_2 plant.**

- **Propose a strategy for the next 5 years of TiO_2 production at the site.**
  You have to recommend either the development or closure of the current sulfate process plant and whether or not to construct the (expensive) chloride plant at the site. Remember there will be a big political and public pressure on TI so the **environmental, employment** and **public safety** issues need to be considered**.** In addition, there is considerable pressure from the management to project an **economically viable business** into the **future**.

- **Presentation of Recommendations**
  Your spokesperson must present your proposals for the next 5 years to a panel of higher managers (2 or 3 tutors) justifying all your decisions. It is important that you state the group decisions in a coherent and persuasive manner.



Evening Herald

Volume 17 Issue 25

Serving the County of Midshire.

Local Elections Loom

Local MP for Beauport East, Simon Ford officially opened his election campaign on Tuesday to a packed hall. As he put it 'the two biggest issues facing the town today' are unemployment and the environment. A representative of the nearby nature reserve said later that he was encouraged but remained yet to be convinced.

'Industry must clean up act'

After a lengthy investigation, the Midshire Water Authority has condemned local industry for its poor pollution record.

A report issued this week highlights the need to clean up the Coley River and Estuary. Local environmental groups (supported by MP Simon Ford) have called for a dramatic reduction in waste discharged into the river over the next 3 years.

A further investigation is to follow and all industries have been asked to provide an environmental statement on their present and future plans to clean up the river.

A team of experts is currently investigating the effects of pollution on local wildlife at the Crook Point Nature Reserve.

The report also blames farmers for the worryingly high levels of phosphates in the nearby Gottland Water. This is not expected to help the rising conflict between the rural and urban communities.

Residents Fear Poison Gas

Local residents of the Riverside Estate have formed a protest group. They are concerned to read about a recent accident at a European chemical plant owned by Titan Industries who have recently acquired the Stoneyhill site. System failure was blamed for the uncontrolled release of an acid cloud from the titanium dioxide plant.

Mrs K. Andrews (78) spoke for the concerned residents, "This could happen here and I always sleep with my window open". Reports of the accident were posted through many doors in the area by an unknown pressure group.

Local Success Stories

This week our weekly feature highlights two different stories of recovery in the local area.

Workers Save Mill

Two months ago, the Paperpak Ltd. paper mill, west of Beauport faced almost certain closure. Today, however, managers are discussing expansion plans after securing a new contract with the government. Paperpak Ltd. will supply high quality paper for use in official documents in a 10 year deal of undisclosed value.

A spokesman on behalf of owner John Tate said 'The credit must go to our workers who have put in a great deal of extra work over the last year.' Paperpak is hoping to employ 100 more staff on the completion of the expansion work which is necessary to equip the mill to supply the heavyweight 'whiter than white' paper required.

Refuge For Nature

Our second success story this month involves the renovation of a large piece of land to the west of the town. The windswept marshes and sand dunes of Crook Point would still be an eroding wasteland if it hadn't been for the discovery of local fireman

Ted Smithers (32). 'I was walking my dog when I saw a funny looking toad. I didn't think much of it, but told the wife'. Judith (29) later went back with a book and told us, 'The toad turned out to be a protected rare breed and soon the place was full of biologists'.

The nature reserve was opened 14 months ago and has seen thousands of visitors including a regular stream of school 'field trips'.

Manager Jane Chapel told our reporter, "We wanted to both protect the wildlife and provide a fun day out for all ages". Even the staff are surprised at the popularity of the project which is drawing people from all over the region.

The purpose built visitor centre will soon be extended to provide another restaurant and a huge interactive nature exhibition. There is also talk of building a 'sea life' centre and a small theme park to the south of the reserve. The reserve is home to many rare species including red squirrels.

Next week

"I was given 3 months to live.....in 1957", a local farmer's battle to prove the doctors wrong.

Political Row over Water Treatment Plant

At a recent dinner, MP Simon Ford claimed the soon to be opened water treatment plant as part of his 'Environment and Employment' campaign. However the opposition claim that the Beauport East MP has had little to do with the development until recently.

The plant should be operational within 12 months and should have a major effect on the state of the estuary.

Titan to Send in Top Management Team

US based Titan Industries is to send in experts to decide on the future of the Stoneyhill titanium dioxide site which it bought recently. Much ill feeling has surrounded the take-over but as union representatives said yesterday, "We can only wait and see what will happen".

News in Brief

Cheaper Power

Midshire Electricity announces cheaper electricity for it's industrial customers in an attempt to encourage more industry to the area north of the estuary.

Farmers Join Forces

A group of local farmers have joined forces, concerned with the effect of local industry on their land, crops and livestock. The group are thought to have considerable political influence and met with MP Simon Ford yesterday.

Unemployment Down Again

The fall in unemployment is mainly due to the surprising growth in tourism and related services as a result of the flourishing nature reserve.

The Titan Project

Titan Industries have decided to build a new chloride plant so they require the setting up of new laboratories and methods.

Your task is to recommend a method for the determination of chloride ions in the aqueous effluent.

The Titan Project

SCIENTIFIC SKILLS

- industrial chemistry
- health and safety
- statistics
- compare analytical techniques
- data analysis / interpretation
- types of error
- accuracy and precision

TRANSFERABLE SKILLS

- working with others
- communication
- decision making
- plotting graphs
- using spreadsheets
- analytical/critical thinking
- time management

What you need to do

Survey analytical techniques for chloride

Compare the analytical methods.

Consider the terms accuracy and precision.

Consider what other factors contribute to the choice of an analytical method

Propose and justify your method of choice

Present your recommendations

Survey of Analytical Methods for Chloride

Following your recommendations that have been made to the board, Titan Industries have decided to build a new chloride plant and refurbish the current sulfate plant. This requires the setting up and refitting of the Process, Quality Control, Environmental Monitoring and Research Laboratories.

You have been directed to investigate the planning and set up of the Environmental Monitoring Laboratory for the new chloride process. This is required to meet the stringent environmental legislation and to allay fears of the public to the potential environmental damage from release of chloride ions into the river.

Investigate the methods that could be used to determine chloride ions in the effluent stream.

Consider the following: -

- The advantages and disadvantages of the methods.
- What makes a good method.
- The criteria you would consider when choosing a suitable method.

Present your findings in the form of a short group report.

NOTES

Choosing a Method

1. Give a definition of accuracy?

2. Give a definition of precision?

3. A standard contained 42 mg / l of chloride ions. Five analysts each performed 6 determinations on the same day with the following results.

Analyst A	42.5	41.6	42.9	41.9	41.1	42.2
Analyst B	39.8	43.6	42.1	40.1	43.9	41.9
Analyst C	43.5	42.8	43.6	43.1	42.7	43.3
Analyst D	35.0	43.0	37.1	40.5	36.8	42.2
Analyst E	42.2	41.6	42.0	41.8	42.6	39.0

   Comment on the accuracy and precision for each of the sets of results.

4. How would each of the following influence your confidence in the accuracy and/or precision of the measurement?
   a. Perform the analysis in duplicate.
   b. Perform the analysis in triplicate.
   c. Use an additional method to calibrate your instrument.
   d. Another chemist repeats the measurement using the same procedure
   e. Use two different procedures to obtain the value under consideration.

5. You are required to use an accurately known amount of ethanol (about 5 ml)
   a. Would you do this by volume or weight? Why?
   b. Outline a procedure you would use.
   c. What confidence would you place on the value you obtained?

6. You obtained two values for the purity of an aromatic carboxylic acid. The HPLC method with UV-visible detection gave you 0.5% impurities in the sample and the titration with sodium hydroxide gave it to being 99.8% pure. Can you suggest the reasons for the differences between these figures?

NOTES

A COMPETENT analytical chemist produced the following data based on the methods in *Handbook of Anion Determination* by W.J. Williams

Gravimetric Method

Add 1 ml of 50% nitric acid to 100 ml of water sample. Slowly add with stirring a slight excess of 0.1 M silver nitrate (about 10 ml) The insoluble colloidal silver chloride is formed initially and coagulated upon heating. Test the precipitation by adding a few drops of silver nitrate and allow to stand for 1-2 hours. Filter through a weighed sintered glass crucible, washed with dilute 0.01% nitric acid and dried to constant weight at 110°C for about 1 hour.

$$Ag^+ + Cl^- \rightarrow AgCl\downarrow$$

Interferences are iodide, bromide, and thiocyanate. Tin and antimony may also cause interferences. Precision is considered better than 0.1%. The following masses were determined four times for each of the chloride standards.

50 mg/l std	100 mg/l std	200 mg/l std	400 mg/l std	800 mg/l std
0.0203	0.0399	0.0805	0.1591	0.3200
0.0200	0.0401	0.0810	0.1596	0.3199
0.0202	0.0398	0.0807	0.1593	0.3202
0.0201	0.0396	0.0808	0.1596	0.3200

Titration: Mohr Method

Add 1 ml of chromate indicator [4.2 g potassium chromate and 0.7 g of potassium dichromate in 100 ml of water] to 100 ml of the water sample. Titrate with a 0.05 M silver nitrate solution until the precipitate turns from yellow to a permanent reddish brown due to the formation of silver chromate.

$$Ag^+ + Cl^- \rightarrow AgCl\downarrow$$

Interferences are bromide and iodide. Also some other metal ion. The following titres were determined four times for each of the chloride standards.

Blank	50 mg/l std	100 mg/l std	200 mg/l std	400 mg/l std	800 mg/l std
0.0	2.80	5.75	11.75	23.65	47.70
0.0	3.10	5.95	12.00	24.15	48.05
0.0	3.25	6.00	11.85	24.30	47.85
0.0	2.95	6.35	12.20	23.85	48.30

For each of the methods.

1. Plot all the data. Is it linear?
2. Draw line of best fit.
3. Calculate the mean ($\bar{x}$), standard deviation (s) and relative standard deviation (RSD) for each standard.

Mean	*Standard deviation*	*Relative standard deviation*
$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$	$s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n}}$	$RSD = \frac{s}{\bar{x}} \times 100\%$

4. Use the graph to determine the concentration for the mean for each standard.
5. Calculate the concentration of chloride for the mean for each of the standards using the details in the procedures.
6. Comment upon the difference between those values determined from the graph and the calculated values.
7. Plot the calculated concentrations for one method against the other.

Spectrophotometric: Mercury (II) Thiocyanate Method

Place a 200 ml aliquot of the water sample into a 250 ml graduated flask, add 2 ml of 0.025 M ammonium iron(III) sulfate in 9 M nitric acid, followed by 2 ml of a saturated solution of mercury(II) thiocyanate in ethanol. After 10 minutes measure the absorbance of the sample solution against the blank in 5-cm cells.

$$2\,Cl^- + Hg(SCN)_2 \rightarrow HgCl_2 + 2[Fe(SCN)]^{2+}$$

The following absorbances were determined four times for each of the 50, 100, 200, 400 and 800 mg/l chloride standards.

Blank	50 mg/l std	100 mg/l std	200 mg/l std	400 mg/l std	800 mg/l std
0.008	0.136	0.231	0.407	0.822	1.496
0.002	0.129	0.245	0.428	0.868	1.443
0.004	0.141	0.256	0.437	0.830	1.452
0.011	0.120	0.222	0.454	0.845	1.474

1. Plot all the data. Is it linear?
2. Draw line of best fit.
3. Calculate the mean, standard deviation (s) and relative standard deviation (RSD) for each standard.
4. Use the graph to determine the concentration for the mean for each standard.
5. Plot the values taken from the graph against the values determined for the gravimetric method by calculation.
6. Comment on the graphs of the three methods.
7. Discuss which method would you employ in the Environmental Monitoring Laboratory.

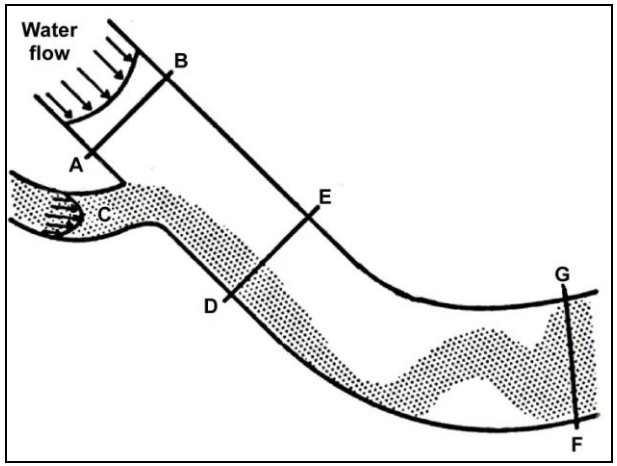
NOTES

Problem Solving

In setting up the Environment Monitoring Laboratory for Titan Industries, the following need to be considered.

Sampling

Titan Industries produce titanium dioxide by the sulfate process. There is a constant discharge of liquid into the local river. This consists of sulfates and suspended solids from the process.



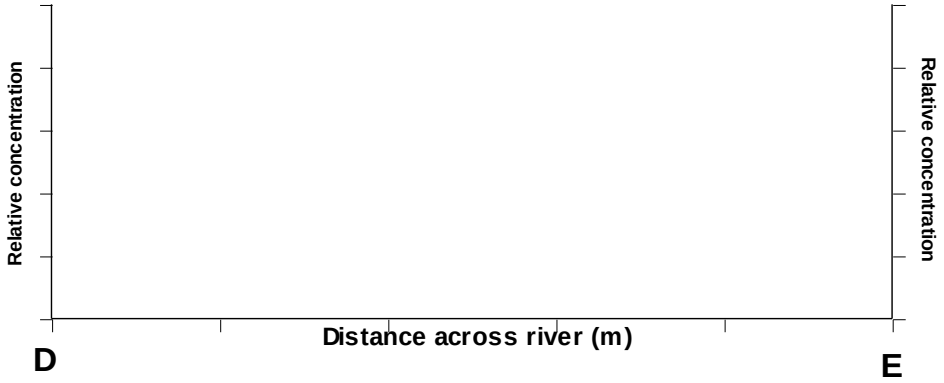
1. Where would you sample so that you could gauge the base levels for the river?
   a. Downstream before the bend (D-E)
   b. At the Outflow pipe (C)
   c. Downstream after the bend in the river (F-G)
   d. Up-stream (A-B)

2. Where would you sample the outflow?
   b. Up-stream (A-B)
   c. Downstream after the bend in the river (F-G)
   d. At the Outflow pipe (C)
   e. Downstream before the bend (D-E)

3. Where would you get a direct measure of concentration in the river?
   a. Downstream after the bend in the river (F-G)
   b. Up-stream (A-B)
   c. At the Outflow pipe (C)
   d. Downstream before the bend (D-E)

4. Could sampling point C be related to the final concentration in the river? If so what further information would be required?

5. Draw a profile of the pollution levels at point D-E



6. If you only sampled at F-G, would you be certain of the location of the discharge point?

Converting Units

Many of the problems with environmental monitoring concern dealing with different units and attempting to explain the results to non-chemists.

7. These are some results from various analyses that require conversion for a report you are preparing for Titan Industries.

parts per billion (ppb)	parts per million (ppm)	grams per litre (g/l)	% weight per volume (w/v)
2.3×10^{6} ppb	2.3×10^{3} ppm		
	0.9 ppm	9×10^{-4} g/l	
212 ppb			2.12×10^{-5} % w/v
	4.1×10^{4} ppm		4.1% w/v
		1.031 g/l	0.1031% w/v
1.2×10^{5} ppb		0.12 g/l	

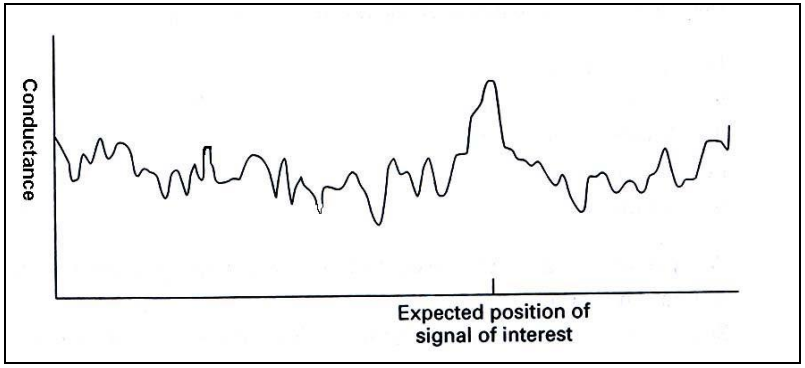
Limit of Detection

Limit of detection and limit of determination are often confused especially by the non-analytical chemist. They are defined in terms of the signal to noise ration (S/N). The former is always larger than the latter.

9. What would is the definition of Limit of Detection?
    a. Two times the standard deviation of the noise.
    b. Three times the standard deviation of the noise.
    c. Can just be distinguished from the noise of the blank.

10. What would you consider as a sensible Limit of Determination?
    a. Two times the standard deviation of the noise.
    b. Three times the standard deviation of the noise.
    c. Can just be distinguished from the noise of the blank.

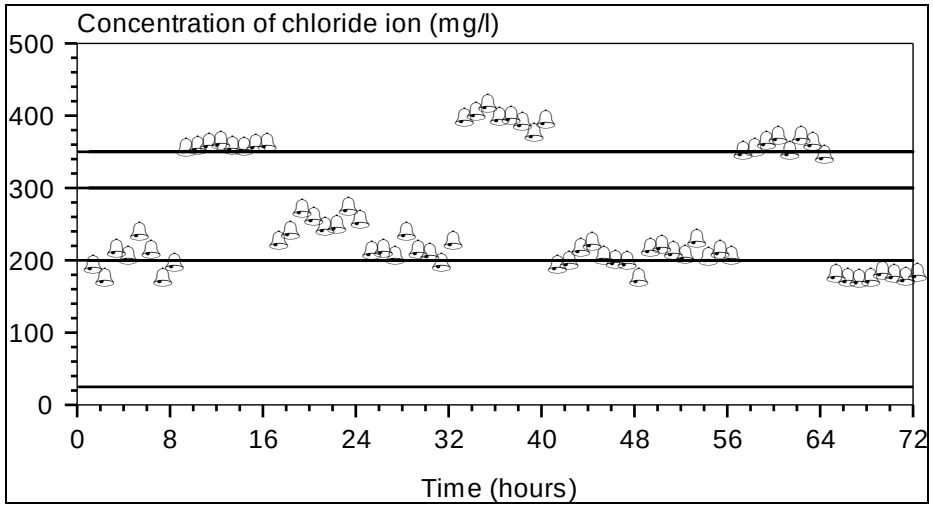
11. A chromatograph from the ion chromatography of chloride in the effluent stream is shown below.



    a. Do you think there is any chloride present in the effluent?
    b. How confident are you that you have detected chloride?
    c. Is this at the limit of determination?
    d. Would you be willing to quantify that amount of chloride present?
    e. How would you choose the base line?

Control Chart

12. A Shewart control chart for chloride ion in effluent was produced over a three-day period by another Titan Industries plant.



    a. Suggest possible reasons for the nature of the plotted results.
    b. How could you argue that you are not above the critical value of 350 mg/l?

Costing

Your line manager has asked you to consider supplying contract analytical services to different customers.

13. Give two examples of a fixed cost within an analytical laboratory?

14. Give two examples of variable costs with the analytical laboratory.

15. What would you take into account when setting a realistic price to cover your costs for a single analysis of Cl^- in effluent by ion chromatography?

16. How would you justify charging a different price if you were providing a regular analysis of Cl^- in effluent by IC for an external customer?

17. Could you justify charging a different price to a customer within Titan Industries for Cl^- in effluent by ion chromatography?

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Classification	Case Study
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