4.1 - General principles of product development

**General**

This chapter presents the main principles underlying the activities of the Dead Sea Bromine Group and, for the most part, of many other companies as well. It will familiarize you with many new concepts in industrial language in general and in chemical industry language in particular. Any new procedure or successful development of a new product starts with an idea and culminates in the sale of the product. This is a long and exciting road that requires teamwork, brainstorming, creative thinking processes and making difficult choices.

From start to finish a project can be divided into a number of principal stages:

<table>
<thead>
<tr>
<th>Research and development:</th>
<th>initiation, checking and preliminary screening</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>laboratory research</td>
</tr>
<tr>
<td></td>
<td>pilot development</td>
</tr>
<tr>
<td></td>
<td>preparation of project plan</td>
</tr>
<tr>
<td></td>
<td>registration or licensing¹</td>
</tr>
<tr>
<td>Product management:</td>
<td>approval for investment in building</td>
</tr>
<tr>
<td></td>
<td>production facilities</td>
</tr>
<tr>
<td></td>
<td>planning and design</td>
</tr>
<tr>
<td></td>
<td>building</td>
</tr>
<tr>
<td></td>
<td>running the process</td>
</tr>
<tr>
<td></td>
<td>product manufacture</td>
</tr>
<tr>
<td></td>
<td>regular sales</td>
</tr>
</tbody>
</table>

All project stages are conducted while adhering to quality assurance standards, which will be explained later in this chapter. One of the main principles of the quality assurance concept is that results and objectives are checked after each stage, followed by a decision whether to continue the process, to stop it or to complete certain tests before passing on to the next stage.

The research and development stages are evaluated by senior team members including management and marketing people, research and development representatives, engineers, environmentalists and safety experts who perform different functions. If necessary, and depending on the subject, other employees are appointed. The team members invest much effort in trying to foresee and

¹ Safety aspects and environmental influences are tested during the entire life cycle of the product.
solve problems and discussing the risks and uncertainties surrounding the technological implementation, marketing and economical aspects of the project.

After the project has been approved, the remaining **product management stages** are completed by an interdisciplinary team including marketing and production staff, research and development personnel, engineers and, if necessary, representatives of the analytical and other laboratories, and others. In this chapter we shall try to clarify some of the general principles underlying the long process leading from *idea to product*.

The Spectrum site in Ramat Hovav – Pilot Plant and its laboratories

**Testing the idea**
The initial stage involves examination of the initiatives and novel ideas for the **development of a new product** or improvement of an existing product or process. At this stage the marketing potential and existing technologies are evaluated, initial laboratory tests and preliminary research are conducted and the possibilities of implementing the different ideas are assessed. All this is done without losing sight of the business strategy and goals of the company.
Aspects to be considered at this stage include:

- Manufacturing a new product for a known application
- Manufacturing an existing product for a novel application
- Manufacturing an existing product by a novel process
- Manufacturing a new product by a novel process

Right at the early stages of decision-making, marketing and economic factors are evaluated to try to answer the following questions:

- Is there a demand for the product?
- Who are the potential customers?
- What is the size of the market?
- Who are the competitors?
- What alternative products exist and what are their price levels?
- How big is the investment needed?
- What is the current price of the product and what are the expected profits?
- What are the building and operational schedules?
- What is the expected return-of-investment period?

All this is done while potential financial resources are being sought: private financing, governmental financial sources, bank loans, cooperation with other companies or foreign investors, etc.

A novel application may require manufacturing a product with a different purity, involving a change in the manufacturing process. For example, products scheduled to be used as food additives must be of very high purity.
From idea to laboratory

If a decision is reached, after the initial investigation, to continue to the next stage and to test the idea more thoroughly in the laboratory, the appointed interdisciplinary team next prepares a detailed working plan including all the aspects discussed earlier. Each new project or idea involving the development of a new product, unknown production process\(^3\), product improvement or existing process, starts in the research laboratories\(^4\) of the Dead Sea Bromine Group or in the central laboratories of the parent company, Israel Chemicals Inc. (ICI). A new product is not necessarily a novel and unknown product; it may be a known or familiar product that the company wishes to test as a possible addition to its product range.

The investigators in the research laboratories try very hard to prepare new compounds and to study their properties, test different production methods, screen patents\(^5\), identify potential safety hazards by reviewing the literature and start to map out the required and available technologies. They are further engaged in developing analytical methods\(^6\), looking for suitable construction materials that can withstand the reaction conditions, etc.

The laboratory experiment is the first and indispensable step to study the reaction and to find suitable reaction conditions. At this stage small-scale experiments are conducted and all chemical aspects are tested. Problems and obstacles that may appear when the processes are scaled-up are also investigated to some extent. Sometimes during the laboratory experiments a unique idea emerges concerning new materials, new procedures, a new technology, etc. Such ideas are patented to protect them against copying or scientific theft.

Testing of processes in the research laboratory usually proceeds with standard equipment (glassware, magnetic stirrers, small heating units etc.), and relatively simple working methods.

Even at this early stage the profitability of the process is evaluated and assessments are made of raw material costs, inputs and expected product price. These assessments are made under different assumptions of yields (70%, 90%) for the planned process.

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\(^3\) There are international companies that sell knowledge and/or production facilities for the manufacture of different products. These are usually products manufactured in large quantities, i.e. commodities.

\(^4\) IMI Research Research Institute, Haifa (http://www.tami-imi.com).

\(^5\) See Appendix C: “What is a patent?”

\(^6\) Analytical methods: tests to identify and accurately quantify substances.
Although the laboratory process is carried out batchwise, one of the questions asked at this stage is: should we plan a batchwise or continuous process? The process engineer, who is a member of the interdisciplinary team, helps the chemists to identify technical and engineering problems of the planned processes, by asking questions such as:
- How to transfer materials from one reaction vessel to another?
- How to mix them?
- How to filter them, etc.?

Even in these early stages considerable efforts are made to prepare risk assessments, to identify potential environmental problems and to suggest solutions to questions such as:
- What should be done with byproducts or undesirable products formed during the process?
- How to get rid of toxic gases?
- What to do with hazardous waste?
- How to carry out the process safely?
- How to conduct in-process control of the various stages, etc?
From laboratory to production

During the conversion of a laboratory process to an industrial one many problems may arise that did not originally appear during the planning of laboratory systems. In most cases it is impossible to copy or scale-up the systems and to carry out the process exactly as in the laboratory. Most problems are the result of differences in equipment construction and in quantities, and in the degree of purity required of the product. Laboratory processes involve small amounts of material, while industrial processes generate large amounts of material. In the initial stages of laboratory research, process yield or product purity is not of crucial importance; the aim is to prove that the process is chemically feasible. In the transition of a laboratory process to an industrial process all the different stages and systems must be changed to adapt them to the goal of obtaining the highest possible yield of the product at the required degree of purity.

Production planning involves manufacturing increasing amounts of product and increasing the size of production facilities. This transition from laboratory scale to industrial scale is called scaling up, and the different stages of this process are called scaling up stages.

**Scaling up:** Increasing the amounts and equipment size in the transition from laboratory synthesis to industrial production.

To obtain the highest yield of product at the required degree of purity different processes are applied, consisting mainly of separation and recycling steps. The overall process is called **workup**.

**Workup:** Series of procedures performed after termination of the reaction aimed at obtaining the highest amount of product at the necessary degree of purity.

The workup process should provide answers to the following questions:
- What is the order of raw materials added to the reaction container?
- How are the raw materials brought / added to the reaction container?
- How to heat?
- How to cool?
- How to mix?
- Which separation methods to use?
- How many separation steps are needed?
- How to filter?
- How to crystallize?
- How to dry?

All these questions are aimed at obtaining a reasonable amount of pure product. Scaling-up, or the transition from a laboratory system to an industrial plant, is usually not performed directly but in a number of different stages. It is best to apply a stepwise system that increases in a ratio of 1:10, but it is not always practicable to go through all the steps. In most cases a bench scale set-up, 1/1000 to 1/100 the size of the industrial plant, is built after the laboratory experiment, followed by a pilot plant, at a size of 1/30 to 1/10 of the industrial plant. The latter simulates, on a small scale, all the engineering stages of the final industrial plant, aimed at minimizing the uncertainties surrounding the building of the final plant. The individual stages are regularly changed and adapted, and both the process and the equipment may be modified with consequent changes in product quality. Only after having gone through all these stages is the final industrial plant built.

**Scaling-up stages:**

- Laboratory experiment
- Bench scale set-up
- Pilot plant
- Industrial plant

Titrination system at “Spectrum” laboratories
An additional and very important advantage of the pilot plant is the ability to obtain samples of the product of a quality similar to that obtained from the final production facility. It is common practice to give these samples to customers for testing and evaluation before taking the final step of building the industrial plant. This method reduces economic risks and has a clear marketing advantage:

- In-house and customer testing of product quality
- Compliance with internal and external test standards
- Marketing research
- Final establishment of product and process specifications
- Updating of business plan

The building of a pilot plant involves considerable investment of cash and time to evaluate processes and construction materials. This has the advantage of limiting the problems that may arise during final production. Detecting problems and learning lessons in time allows for making corrections and reduces the difficulties and financial losses that may otherwise occur. Nevertheless it is important to remember that even a pilot plant is not completely identical to the final plant, and that it will not necessarily reveal all the potential problems of an industrial plant working at full capacity.

It is unusual to omit bench scale and pilot stages, but in the past direct switches to large-scale production have been made to save time and money. As a result a multitude of problems often arose causing financial losses, which could have been avoided if the scaling-up stages had been properly executed. Experience has proven that problems must be solved before large investments are made in construction, equipment etc. The words of the inventor of Bakelite, Leo Baekeland (1863-1944) speak for themselves: **It is preferable to err on a small scale and to earn on a large scale.**

Even after suitable solutions have been found for all the problems detected in the scaling up stages and the final plant is being built, the work is not yet over. The systems become more sophisticated, new tools and materials are discovered and better solutions are sought. It is an unending search for improvement and increased efficiency.
Main variables taken into account in the scaling up process

Raw materials
Choosing raw materials in the laboratory is much simpler than in industry. Generally speaking when producing a small amount of material in the laboratory, the price of the raw materials does not pose a significant problem. On the other hand in industry, where profitability is a major objective, the choice of raw materials is of crucial importance. The choice of raw materials can also influence the process itself, because sometimes it is possible to get raw materials of different purities, or with different concentrations of impurities (as we shall see from the example in Section 5.2, Page 174).

Reaction conditions and reaction rate
The feasibility of any process is characterized by two parameters:

**Thermodynamic control**: Concerns the spontaneity of the process and is determined by the value of the change in free energy of the process at a given temperature.

**Kinetic control**: Concerns reaction rates and is determined by the value of the free energy change of activation at a given temperature.

Decision will take account of thermodynamic factors expressed by preference for a process that increases the entropy (e.g., in a reversible reaction in which gases participate, the entropy increases by intensifying the reaction in which more molecules are formed), or from kinetic factors (such as accelerated reaction as a result of raising the temperature) or from other factors (such as preventing loss of material by evaporation or maintaining safety).

In a laboratory experiment the time factor is usually not very important. In industry, by contrast, time plays a vital role, or more precisely, the amount of product obtained per unit time\(^7\).

\(^7\) This amount is called output. For definition see Page 127
This is especially important in the manufacture of large amounts of products. The time factor also plays a role in most of the previously mentioned considerations: choice of raw materials, establishing reaction conditions, choice of technology, equipment etc. All these factors have to be taken into account in order to attain the best possible conditions without increasing the costs too much. The reduction of reaction times can be accomplished by the choice of technology or by changing the actual process. If the products are formed in fast reactions, the reaction time can be decreased by increasing flow rate or by shortening the incubation time of the reactants in the different containers. If the reaction is slow, the use of a suitable catalyst can shorten the process time.

In the previous chapters on chemistry you learned about the effect of a catalyst on the reaction rate. The catalyst lowers the process free energy of activation (or some intermediate phase of it) and so shortens the time required to terminate the reaction. At the end of the process the catalyst returns, usually to its original state, and thus can fulfill its task repeatedly.

**Catalyst:** Substance added to the reaction to increase the reaction rate

**Free energy of activation:** The energy needed to bring the reactants to the transition state enabling product formation to take place.

- Can the addition of a catalyst to the process change the amount of product formed? Explain.
- Consider two possibilities:
  - A catalyst is added without changing the temperature
  - A catalyst is added and the temperature is changed
- Discuss two cases:
  - A reaction in which only one product is formed.
  - A reaction in which several products are formed.

In industry use is often made of solid catalysts that absorb the reactants onto their surface and so facilitate the formation of intermediary products with a lower potential energy than those that are formed without the catalyst. Catalysts with such a working mechanism must have a large surface area. This is accomplished by a porous structure or by the use of many small particles. Several factors gradually lower the efficiency of the catalyst. In practice every catalyst can fulfill its task efficiently for a given time period.
The decreasing efficiency of a catalyst due to absorption of undesired substances into its surface is called **catalyst poisoning**. Other reasons for decreasing catalyst efficiency are evaporation of the catalyst at high temperatures, structural changes in the catalyst or other technical reasons causing catalyst damage, and the need for a change of catalyst which is necessary from time to time.

**Catalyst poisoning:** A decrease in catalyst efficiency due to absorption of undesired substances or other factors into its surface area that interfere with its function.

The industry usually finds economical compromises that take into account the cost of the catalyst and its effective lifespan. In some cases the catalyst is **reactivated** or used for other purposes to reduce costs.

**Catalyst recovery:** Restoring the activity of the catalyst

Often, besides the reaction yielding the desired product, competitive reactions occur in which other, undesired products are obtained. These occurrences lower the yield of the desired reaction. Correct choice of temperature and/or of a selective catalyst that lowers the free activation energy of the desired reaction (without essentially changing that of the competitive reaction) can guide the reaction in the desired direction. That way a reaction takes place that initially had no higher **kinetic preference** or initially lower **thermodynamic preference**.
The next figure schematically demonstrates such a situation for two competitive reactions:

- Is it useful to add a catalyst in case products (I) are desired? Explain.
- Is it useful to add a catalyst in case products (II) are desired? Explain.
- At which temperature does the thermodynamically preferred reaction takes place?
- At which temperature does the kinetically preferred reaction takes place?

In previous chapters you learned that in reversible reactions in which gases participate, a change of pressure might have an effect on product concentrations. You also learned that in reversible reactions the amount of product could be manipulated by changing the temperature.

Is it useful to increase the pressure or the temperature? This a more complicated question, which depends on economic factors that also take into account various costs involved such as: energy costs, costs of changing construction materials, costs connected with the choice of suitable technologies etc.

- How does a decrease/increase in temperature influence the amount of product formed in a reversible process, that is in equilibrium, when the direct process is exothermic? endothermic?
- How does a decrease/increase in pressure influence the amount of product formed in a reversible process that is in equilibrium when:
From idea to product

(a) there is no difference in the number of moles of gases participating in the reaction?
(b) there is a difference in the number of moles of gases participating in the reaction?

- What are the variables to be examined in order to lower the temperature?
- What are the variables to be examined in order to raise the temperature?
- What are the variables to be examined in order to raise the pressure?
- What are the variables to be examined when we want to lower the pressure?

Equipment and installations
A production process can generally be considered to consist of a number of primary operations, which include moving materials (raw and intermediary materials or products), mixing materials, filtering, condensation, crystallization, distillation, drying, packaging, etc. For each operation suitable equipment must be chosen, whose efficiency, corrosion-resistant properties, price and maintenance costs must be examined. This selection procedure is the task of the chemical engineers who plan the plant.

Equipment choice and adaptation to primary operations depend on a number of factors including:
- Amount of material
- Physical state of material
- Required resistance
- Costs (building, operation and maintenance)

The principal factors influencing the choice of equipment are the type of material and amounts to be produced. Sometimes, when very large amounts are manufactured, a number of smaller systems are utilized, operating in parallel, and so if there is a defect in one of the systems, another continues to work. Information on the physical state of the materials is important for the planning of different operations, such as continuous addition of the material to the reaction vessel, stirring, pumping, filtration, etc.
The use of resistant equipment means selecting the construction materials to suit the reactants and reaction conditions. This is one of the main problems to be reckoned with when selecting equipment for industrial processes. As mentioned before, in the laboratory we usually make use of standard, special glass-made equipment and tools. Glass has the advantage that it is resistant to high temperatures and to many highly corrosive substances. An additional advantage is its transparency, which makes it possible to watch what is happening
in the vessel during laboratory experiments. It is generally not practical to use glass equipment for industrial installations, but sometimes there is no alternative (as we have seen in Chapter 3, which discusses bromine production).

The following variables influence the choice of construction materials:
- The size and mechanical strength of the installation.
- Temperature and pressure conditions inside the installation
- Specific corrosion problems
- Cost and relative efficiency of suitable construction materials

For example, resistance to high pressure requires the building of installations with sufficient mechanical strength. In such cases one often uses stainless steel, which is an alloy composed mainly of iron, nickel and chromium. The shape of the vessel can also influence its strength. A vessel or container intended to withstand high pressure should preferably be round, because this imparts strength. Such a vessel can have a less expensive, thinner wall.

Often there are also specific corrosion problems connected with the materials involved in the reaction, products and the reaction conditions, for example in work with halogens, aqueous solutions of acids, etc. In such cases stainless steel is unsuitable and alternative solutions must be sought, such as the use of special plastic materials, special alloys, various coatings, etc.

When a number of requirements converge, such as corrosive materials, high temperatures and high pressures, the adjustment problem becomes much more complicated. In such cases particularly resistant, often very expensive, materials must be applied (e.g., the titanium or tantalum alloys referred to in Chapter 3 in connection with the new bromine plants).

One of the challenges for the investigators working in this field is to find construction materials that fulfill all the requirements in the best possible way. The selection of equipment parts for different industrial processes (such as: pumps, filters, drying ovens, etc.) is a complicated procedure demanding much knowledge and experience. The selection procedure does not only involve construction materials, but other system components as well, which must be compatible with the unique properties of the materials participating or formed in the process.

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8 For example, this is the way that storage tanks for high-pressure gases, such as ammonia, chlorine, cooking gas, etc., are built.
For example, if the product is solid, the size and moisture content of the crystals are among the more important parameters. Although many methods exist to dry materials, not all of them are applicable. Several cases are known of processes that have gone awry due to the failure of the material to crystallize or inability to obtain it in a sufficiently dry form. The choice of a drying method and relevant equipment must be compatible with the condition of the product and product specifications as ordered by the customer.

**Energy**

Heating and cooling in the laboratory can be performed in different ways, but the costs are usually not important. In production, however, energy costs are of crucial economical importance.

- Which factors need to be considered when choosing a heating method? Cooling method? Give examples of different heating and cooling methods.

During the scaling-up stages, the energy problems posed by increasing amounts and equipment size must be solved. During the engineering planning stage, account must be taken of variables such as heating or cooling rates, which depend, among others, on the capacity and surface area of the vessel. This ratio between capacity and surface area varies and depends on the shape of the vessel.
From idea to product

For example, if the radius of a round-shaped vessel is enlarged 10 times, its capacity will increase 1000-fold and its surface area only 100-fold. The amount of material that can be introduced in the vessel is increased 1000 times and so is the amount of energy emitted or needed for the process. On the other hand, the heating or cooling rates that depend on the vessel’s surface area are increased only 100 times.

Cooling or heating methods may also change in accordance with the reaction conditions, the temperature inside the container and the desired degree of cooling or heating. Various means may be chosen, such as: cold or hot air, water at ambient temperature, cold brine (when very low temperatures are required), etc. Examples of this will be presented in Chapter 6, which discusses different production methods.

**Batchwise or continuous process?**

This is a question frequently asked, but the answer is not simple and depends on several factors. A clear advantage of the batchwise method is the easy control of reactant concentrations and the ability to verify termination of the reaction. It is also easier to control reaction conditions (pressure, temperature, pH, etc.). The main disadvantage of the system is that the process is carried out batchwise. Only after finishing one step is it possible to continue to the next. In contrast, in a continuous process the materials do not remain in the containers but continue flowing. The uninterrupted feeding of raw materials generates a continuous flow of products. On the other hand, in a suitably modified, batchwise process more than one product can be manufactured, as opposed to a continuous process that is designed for one product only. Due to these differences a batchwise process requires bigger reaction vessels than an identical continuous process. The ability to scale-down the size of the reaction vessels, and consequently the plant, is one of the advantages of a continuous process.

The planning of a continuous process is much more complicated than that of a batchwise process. In a continuous process a constant flow of materials along the entire production line and stable conditions in all parts of the system must be ensured. A continuous process design therefore requires the presence of pumps and automatic monitoring systems, and must enable remote in-process control of material flow-rates and concentrations, reaction conditions, etc. These requirements relate to each of the variables influencing the process: raw materials, products, cooling water, energy, etc. In a batchwise process, by contrast, sampling is possible and out-process tests can be performed.

The decision to design a batchwise or continuous process usually depends on the...
amounts to be produced and on stability of demand. If there is a lasting demand for large amounts it is generally worthwhile to invest in the more expensive continuous process. A batchwise installation is preferable if the demand for the product is variable and small.

- **Is it possible to know from a flowchart if a process is continuous or stepwise? Explain.**

![Routine maintenance in one of the production installations](image)

**Output and yield**
In a laboratory experiment there are usually no special demands as to amount of product formed and therefore output or yield are not important. On the other hand, a large-scale production plant must be able to generate an output in accordance with market demands and optimal yields to increase profits.

**Output:** Amount of product obtained per unit time. Output can be measured per hour, day, week, month or year. Output of commodities is usually measured in tons or hundreds of tons per year.

In industry the amount of product obtained must be measured relative to a given amount of raw material and this provides a measure for the efficiency of
From idea to product

the process. It is of crucial importance to minimize losses of raw material or products during the entire manufacturing process. Care should be taken to limit the waste of materials to a minimum, therefore suitable reaction conditions, working methods, etc. must be chosen. For this purpose, as we have seen in the previous chapter, we use the concept of reaction yield, which is a measure of the amount of product generated in any stage of the process relative to the amount that should have been obtained theoretically from a given starting amount of reactants. A more important parameter for the amount of product generated in the process is the overall yield.

For calculation of the overall yield we relate to the entire process from beginning to end (including all reaction stages, separation and recycling) as a “black box”. The calculation is performed based on the amounts of reactants entering the process relative to the amounts of products obtained at the end of the process.

Degree of Product Purity

For most industrial products the degree of purity of the material is important. At the same time it is important to note that the purity required depends upon its use. There is no need to invest in highly purified raw materials (that are of course more expensive) or in unnecessary purification steps (each additional separation step increases financial investment) if not required for a particular application. For example, phosphoric acid used for the production of fertilizers can be of lower purity than the same acid used for the production of coca cola. The degree of purity of the product must match customer requirements. This is one of the basic principles of quality assurance, an approach that is being increasingly accepted today in the modern industrialized world and that we shall deal with in more detail later in this chapter.

There are many different purification methods, and they are selected on the basis of types of materials and their properties, the required degree of purity and financial costs. Sometimes the use of different raw materials, or even of the same raw materials from different sources can result in products with different purities. Also, the use of different separation methods may lead to products with
different degrees of purity.

- Give examples of different methods for the purification of:
  - An organic product
  - An inorganic product
- What are your arguments for selecting a particular purification method?

There are additional factors that are of no economic importance in a laboratory process, but carry weight in the industrial process. Most relate to saving on input, such as water, energy, auxiliary materials (solvents, catalysts, etc.) and raw materials, or investment in maintaining safety and protecting the environment.

**Input:** Any economic factor included in the calculation of overall product cost.

**Saving on inputs**

**Water:** In many cases the use of cooling water or drainage water constitutes an important factor in the production costs, and their efficient use improves profitability.

To save water, closed-circuit cooling water is commonly used. The water circulates through the system and is cooled off or heated up accordingly. But, as in many other cases, the solution to one problem sometimes generates another one. Such cooling systems can promote the growth of moulds, algae and microorganisms that may multiply and cause blocking and corrosion of the system.

To prevent these phenomena, suitable disinfectants for the prevention of microbial growth and anti-corrosives are often added to water circulating in closed circuit. In Chapter 5 you will learn extensively about the types and actions of disinfectants, since this is one of the most important areas of activity of Bromine Compounds Ltd.

Drainage water can be saved and therefore reused both by correct planning of the drainage system and by appropriate purification procedures.

**Energy:** Because of the great importance of saving on energy, efforts are made to make the best possible use of energy released from exothermic processes to the advantage of endothermic processes. In industrial plants, one tries as far as possible to prevent wasting energy by transferring heat from hot materials, which must be cooled, to streams, which must be heated. We saw this in the bromine plant, where the thermal energy from the exploited hot brine is used to
heat the brine flowing into the reaction tower. In industry, energy released from exothermic processes is often used to heat water for steam production. In addition, a central water-cooling installation is usually present, satisfying all industrial needs. Such a central installation saves on inputs.

**Auxiliary materials:** As mentioned before, *catalysts* are used in many processes. Even if the catalysts are well preserved and care is taken not to poison them, they gradually become contaminated and different processes slowly reduce their efficiency. Most catalysts are expensive, and therefore it is very important to cut costs in this area and, if possible, to *reactivate the catalyst*. Catalyst recovery is a special process that is usually carried out by the manufacturer. Likewise, it is desirable to *save on solvents*. It should be realized, however, that contaminants accumulating in solvents circulating in closed circuit could, at a sufficiently high concentration, interfere with the process. Occasional purification of these solvents to eliminate the contaminants is therefore needed. Although such purification procedures require additional investments, it should be kept in mind that in addition to their economic importance, recycling rather than dispersal of solvents also helps to protect the environment.

**Spectrum - The Bromine Compounds pilot plant**

Adjacent to Bromine Compounds Ltd. there are special scaling-up facilities, where supplementary tests are conducted to adapt the laboratory process to production on an industrial scale. These are the Spectrum facilities, which house the plant’s pilot plant. In the first stage the process is transferred to the facilities’ laboratory, which is actually a computerized mini pilot plant. It is a sophisticated laboratory equipped with state-of-the-art equipment for further testing of the process after
completion of its initial development stages in the research laboratory. Each stage of the process is tested thoroughly to find suitable raw materials, optimal reaction conditions, required reaction time, auxiliary materials, impurities, etc. All this is done by modifying different parameters, such as reaction conditions, flow rate of materials and reaction times, until optimal conditions are found for formation of the desired product at the required degree of purity. Testing of the different reactants, temperature, pH and other variables is performed by sophisticated probes connected to computers that compile the different parameters over predetermined time intervals, which may be as long as a few days. The data are analyzed by means of special computer programs. This is a very significant and challenging procedure, which eventually leads to the establishment of precise conditions for each stage in the process.

After finishing these test stages in the computerized mini pilot, the process is transferred to the pilot plant for testing on a larger scale. The pilot plant contains different sized systems that more closely resemble the final industrial plant. Here too it is possible to scale up the systems enough to enable the efficiency of the different technologies to be tested. This procedure sometimes lasts several months and its outcome is a process file, containing precise instructions on the planning, building and commercial operation of the industrial plant. All these and other problems are beyond the scope of the chemists and are passed on for action by other professionals, such as chemical engineers, environmentalists, economists, etc. Solutions to these problems are usually examined on their economic merits.
One of the important advantages of a pilot plant is the possibility of getting commercial samples that customers can test in the early stages. Product testing by customers helps to establish whether the product actually suits its purpose, or whether changes should be considered. Providing customers with samples improves the marketing process and enables us to know in advance who will be the customers, what will be their demands, how much product they plan to buy, etc.

How many of the ideas are actually implemented?

In the chemical industry the usual estimate is 1:100 whereas the usual ratio in the pharmaceutical industry is 1:1000. Of every hundred ideas tested in feasibility studies only about forty reach the initial laboratory test stage. About six of these reach more advanced stages of laboratory testing, in which optimal conditions are tested (optimization). Only about two of each hundred ideas reach pilot stage testing and only one of these may reach implementation.

The time needed to go through all these stages from product development to a new product can be more than seven years. Products that are not novel and are also produced by other companies, usually need a shorter period.

Feasibility study - 100
Laboratory - 40
Optimization - 6
Pilot - 2
Production - 1
4.2 - How to achieve overall quality?

Control, quality control, quality assurance and environmental considerations

In this section we present a number of basic concepts on the subject of quality control and the basic principles concerning quality assurance, a management concept adopted by the Dead Sea Bromine Group.

In-process control is an inseparable part of the routine and regular operation of any industrial plant. With the control system we check if all stages of the process proceed as planned. This is especially important for stages demanding special conditions, high-risk stages, stages that determine the yield of the system or those that influence the purity of the product. Control methods are constantly being developed and most systems are equipped with integrated, computerized control systems, which show the operators the actual conditions at different sites in the plant and even make it possible to change certain factors if necessary. Each process is controlled by specific variables. For example: acid-base reactions can be controlled by the pH, exothermic reactions by the temperature, and gas reactions by pressure, etc. Process control includes taking samples at different stages of the process for qualitative and quantitative laboratory testing.

Control room in the plant

The better the in-process control, the more the final product will comply with customer demands, and the higher the overall process yield. To test if the final product indeed complies with customer demands, samples are taken for laboratory testing.
These tests identify the final product, its properties and possible impurities. This helps us to decide whether the process has reached its endpoint and the desired product obtained, or if efforts to further improve the product should be continued.

In the past it was common practice to perform a quality control test on the final product only after the production process was finished. Such a test would reject a shipment if its specifications did not comply with demands, resulting in financial losses to the company and sometimes delays in delivery to the customer. According to this outdated approach quality control served as a selection station for the product without having an influence on the production process itself or on the quality of the product.

Today there is a growing awareness in industry in general and in the chemical industry in particular that quality control alone is not sufficient and that there is a need for quality assurance. As mentioned before, this concept was embraced by the Dead Sea Bromine Group and gradually all its plants have been awarded the international quality assurance standard certificate (ISO 9000). Quality assurance starts with the planning and development of the product and extends to all further activities around the product until it reaches the customer. This is a structural policy of failure prevention and good manufacturing practice that includes process monitoring, data compilation and feedback performance evaluation to correct possible mistakes.

**Control systems:** instruments, tools and procedures for the monitoring of important variables in industrial and other processes.

**Quality control:** test to assess whether product quality at the end of the production process meets specifications or whether the product should be rejected.

**Quality assurance:** systematically planned set of procedures needed to ensure that a product and/or service meet quality standards that fully satisfy customer demands.

Today the entire Dead Sea Bromine Group operates under a set of standard operating procedures that controls every stage and operation in the process according to a system of preset standards, aimed at overall operational and product quality. This includes research and development, planning and building of installations, purchasing equipment and raw materials (including supplier evaluation), production and control, instrument use and laboratory tests,
packaging, storage and transport, training of workers and customers, maintaining safety and environment, etc.
This system considerably reduces final product rejection after much money has been invested in raw materials, energy, and work, and consequently increases company profits. Rather than waiting till the end of the process to assess product quality and to test final product compliance with specifications, each stage is controlled and corrections are made wherever necessary, from the initial to the final stage of the process. Also, preplanned intersections are defined (quality gates), which serve as checkpoints for the results of the previous stage, which must meet defined standards.

The most important characteristics of this approach are:

- A documented system of quality management
- Statistical process control
- Teamwork

This quality assurance policy has been integrated in the task performance and responsibilities of each employee, with emphasis on teamwork. This approach enhances employee involvement in process control and emphasizes the importance of each employee’s personal contribution. It encourages the employee’s initiative in suggesting process development, cost reduction and quality improvement. Every year a quality competition is organized in Israel, in which many companies and organizations participate. In 1998 and 2001 the Dead Sea Bromine Group won this competition.

In recent years there has been an increasing awareness of the importance of safety and environment protection. Consequently, the authorities have established rules for the protection of the environment. These rules lay special emphasis on the:

- Protection against emission of excessive smoke or soot
- Protection against emission of toxic gases into the atmosphere
- Protection against drainage of toxic materials into the waste system
- Protection against seepage of toxic materials into groundwater
- Protection against pollution of rivers, lakes, beaches, etc. by hazardous waste materials.

- How can emission of toxic gases into the atmosphere be prevented? Burning gasoline also emits toxic gases into the atmosphere.
- What are these gases?
- How can this emission be reduced or prevented?
- How can you prevent possible damage caused by uncontrolled drainage of hazardous waste materials?

In March 1997 Bromine Compounds Ltd. was awarded the International Standard of Environmental Management System (ISO 14001) certification, and so became the first chemical plant in Israel to receive this qualification (by the British Standards Institution). The underlying principle of the environmental management concept is the officially endorsed, complete implementation of environmental laws and regulations, with the aim of reducing the risks of damaging the environment and endangering safety.

The Dead Sea Bromine Group accepted this policy of protecting workers and environment, which comprises:

- Protection of the environment in all company activities
- Reduction of pollution (air, water, soil, hazardous waste)
- Protection of employees’ health
- Observing laws and regulations
- Managing the company’s products for the duration of the product’s life
- Protection of natural resources
- Commitment to and provisions for environmental management
- Training and exercises
- Choosing suppliers³
- Information distribution and free communication

³ An important aspect of this principle is the preferential treatment of suppliers and service providers who have a high awareness of the significance of the protection and promotion of environmental values.
The effort and investment demanded to implement these principles are compensated by increased efficiency, quality improvement and the preservation of a greener environment, and often lead to profit-generating savings. It is important to remember that this is a process of continuous improvement, which involves not only plant operations and production, but also forces the company to manufacture only quality products that comply with international standards. This treatment is given to every product during its entire lifespan, from the research and development stage until it is discarded or recycled after its expiry date. This concept, now established in the industrial world and particularly in the Dead Sea Bromine Group, is called product life management.

In the next section we shall present in more detail the general principles of industrial safety and environmental protection and the application of these principles in the Dead Sea Bromine Group.
4.3 - Preservation of safety and environment

General

Safety measures should be taken in almost any area of life, at home, at school, in the workplace, in places of entertainment, etc. In the school laboratory there are clear rules concerning how to behave and work safely.

- What are these rules?
- What safety measures exist in your school?

In industry, safety measures are an integral part of good industrial practice, starting from the research laboratory and including production, transport, marketing and sales. Often safety measures are intimately linked with environmental preservation. An accident or a disaster can endanger not only the employees’ lives, but can also cause damage to the environment.

In many laboratory experiments there is a potential danger of overheating, explosion, leakage, etc. On the other hand, working with small amounts of materials makes it easier to preserve absolute safety. At work, all laboratory and experimental plant employees are obliged to obey the safety rules. Safety problems caused by toxic materials formed during a laboratory experiment are usually easily resolved by working under a hood (if we are dealing with gases) or in other ways (in case of liquids or solids). For example, by letting a hazardous material react with a suitable neutralizing agent, the former can be converted to a harmless material, without the need to consider the price of the neutralizing agent or other factors, such as manageability, etc.

In industry, safety issues include subjects such as:

- Safety of buildings, plants and equipment (prevention of fires, cracks, collapse, etc.)
- Safe handing of hazardous materials
- Safety of processes
- Safety and health protection of plant workers

All these factors can directly influence the environment. Hazardous materials leaking from a cracked pipe can cause air, soil or even groundwater pollution. Insufficiently treated hazardous waste can cause immediate damage, such as an explosion or fire, or long-term damage, such as poisoning of water sources, health damage to residents, etc.
Maintaining safety and protecting the environment will preserve natural resources and prevent **air, water and soil pollution** and damage to **people and their surroundings**.

**In industry**
Safety and environmental questions put their mark on all industrial activity:
- Research and development
- Planning, building and operating
- Production
- Storage (raw materials, auxiliary materials, and products)
- Transport and distribution
- Use of products
- Treatment of emission gases, liquid and solid waste (including packaging materials)

These areas of activity must each be handled in appropriate ways. They include:
- Risk review
- Operating procedures for each individual material or process
- Training of employees/customers
- Warning signs
- Protective measures
- Emergency arrangements

As we have seen, right from the research and development stage, quality assurance and environmental management involve safety and environmental matters, and continue through to the planning, building and operational stages. This is an ongoing activity involving all stages of **production, storage, transport**
and use, QA and environmental management is constantly striving to improve performance. The following scheme illustrates the main safety and environmental subjects under discussion:

**Production**
- Reduction of toxic waste
- Prevention of toxic gas emission into the atmosphere
- Reduction of amount of sewage
- Improvement of existing procedures
- New, environment-friendly, process and product developments
- Proper sewage and waste treatment
- Recycling of materials
- Solvent reuse
- Conversion of byproducts to useful products

**Use**
- Testing of implications for people and environment
- Technological product development
- Technological application development
- Classification and marking
- Labeling
- Safety sheets
- Consumer training

**Storage**
- Storage instructions
- Computerized material monitoring system

**Transport**
- Transport routes (sea, air, land)
- Permits
- Regulations (classification, marking, packaging)
- Safety sheets and safety equipment for transporter
- Emergency services
- Training

The risks must be understood and acceptable solutions found to minimize accidents and damages to a minimum. Nevertheless, companies should be prepared for unexpected accidents.

Manufacturing companies have different systems to cope with safety and environmental problems:
- Neutralizing agents for hazardous materials
- Centralized systems for the removal, absorption and neutralization of hazardous gases
- Air and hazardous gas monitoring systems
- Sophisticated detection and warning systems
- Fire extinguishing systems
- Emergency vehicles

Many company employees are involved in extensive educational and ongoing training activities for the employees, including emergency exercises and instructions on how to handle accidents. In addition, there are plant emergency teams trained to act quickly and efficiently in case of a fault or accident. During a tour of the plant warning signs regarding safety rules are seen everywhere. These signs remind the employees of potential danger and the routine safety measures they should take (for example: wearing helmets, boots, etc.) Fire extinguishers, containers with neutralizers, eyewash devices, emergency showers, etc. can be found in many places in the plant. Fire extinguishers and neutralizing agents must be available at every potential danger spot. Fire extinguishing and neutralizing systems must suit the types of materials and the workplace.

Today at Bromine Compounds Ltd. no process is approved without comprehensive solutions for all environmental problems involved. All substances leaving any production installation (product, byproducts, auxiliary products and whatever waste products formed) have to be treated properly to prevent injury or environmental damage.

Fire extinguishing equipment at the plant
Some plants have been successful in developing techniques for the separation of problematic materials from waste, and converting them to useful products or selling them to other plants (as products or raw material), and so have increased profits. In other plants, methods were developed for the reuse of organic solvents by applying recovery techniques using activated carbon, which absorbs the contaminating materials and releases the pure solvent for reuse. In addition, absorption towers have been built to prevent gas emission and to exploit material recovery. As environmental issues are developing we will discover more cases in which proper treatment of waste may turn out to be profitable.

The profits are doubled: economic profit and environmental profit!

Nevertheless it should be remembered that the solutions to safety and environmental problems must be applicable on a large scale and not be too expensive. High cost could make the whole production process unprofitable. This poses a significant and inescapable challenge for the chemical industry, which on the one hand is required to protect the environment and to obey the laws and regulations, and on the other hand to keep production going and make a profit.

**Experiment: Separation with activated carbon**

a. Prepare a concentrated solution of raspberry juice by mixing 25 ml of water with 25ml raspberry juice extract. Transfer 10 ml of this reference solution to a test tube.
b. Prepare filter paper that fits in a separation funnel. Place the funnel above a chemical beaker or a conical bottle.
c. Dispense one teaspoon of activated carbon in the center of the filter paper.
d. Pour the prepared solution through the filter paper.

- Write down your observations and explain them.
- Are there any observations that you cannot yet explain? Which?
- On what principle is this system based?
4.4 - Toxicology and product registration

**Toxicology:** Science dealing with the toxicity of substances in humans, plants and animals. Toxicology is an interdisciplinary science including chemistry, biological systems and also physiological and biochemical processes in animals and in the human body.

It has been known for many years that all halogens and some of their derivatives are toxic. These materials cause serious damage to plants, animals, microorganisms such as algae and bacteria, and also to humans.

Chlorine gas is an example of a material whose toxicity and reactivity with living tissue resulted in many fatalities when it was used for chemical warfare in the First World War. Yet these same properties of chlorine are exploited for vital human purposes, such as disinfection of drinking water and swimming pools, treatment of waste, etc. Chlorine also plays a very important role in preventive medicine and sometimes even in saving human lives. This is further explained in Chapter 6 which deals with the importance of water disinfectants.

Some of the products, raw materials and intermediary products of the Dead Sea Bromine Group are toxic or hazardous substances. The following table lists data on the toxicity of bromine and a number of bromine compounds:

<table>
<thead>
<tr>
<th>Material</th>
<th>Formula</th>
<th>What happens when exposed to the material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bromine</td>
<td>Br₂</td>
<td>Liquid bromine quickly attacks skin and other tissues and causes irritation and burns that heal slowly. Even a relatively low concentration of bromine vapors causes severe irritation of the respiratory system, impaired breathing, headaches, dizziness, nose bleeds, coughing, vomiting, diarrhea, etc.</td>
</tr>
<tr>
<td>Hydrogen bromide</td>
<td>HBr</td>
<td>Hydrogen bromide gas causes vision problems, skin burns, coughing, shortness of breath, pulmonary edema, damage to intestinal mucosal tissue and diarrhea. A concentrated solution of hydrogen bromide causes severe skin burns and other damage mentioned above, due to high volatility.</td>
</tr>
<tr>
<td>Methyl bromide</td>
<td>CH₃Br</td>
<td>Particularly toxic to the respiratory system. Even at low concentrations the gas causes severe damage to the respiratory system and burns to tissue. It can cause damage to vision, the nervous system, kidneys and respiratory system.</td>
</tr>
<tr>
<td>1,2 dibromo ethane (EDB)</td>
<td>CH₂BrCH₂Br</td>
<td>Toxic upon breathing, swallowing, and eye and skin contact. Can penetrate the skin. Both the vapor and the liquid are highly toxic and cause tissue destruction, vomiting, fainting and dizziness. Causes damage to the liver and kidneys. It accumulates and is mutagenic (causes mutations in hereditary material).</td>
</tr>
</tbody>
</table>
Looking at this table we see that toxicity can express itself in different ways: breathing, swallowing, skin contact, eye contact, etc. A material that is toxic in one way does not necessarily have to be toxic in another way. For example, a material that is toxic when swallowed is not necessarily toxic to the skin. Toxicity of a material is not an absolute term, but is relative to its concentration and application. There are safe and unsafe ways to use or work with any material. It is also important to remember that toxicity depends not only on quantity but also on exposure time to the material (see definitions in Chapter 3 Page 94). Even materials that, on the face of it, look entirely hazard-free may be toxic if used incorrectly.

It may seem preferable not to produce toxic materials. There are organizations in the world that claim just that. If this were the case, mankind would not have enjoyed many scientific and technological achievements and continued to suffer from many insurmountable hardships. Even in areas that we take for granted we would have to retreat and give up comfort, quality of life, health, and many other things. Examples of this exist in almost every aspect of life: medicine, agriculture, communication, etc. A case in point is epidemics of lethal diseases that have been controlled by medicines often containing toxic materials. Are we going to eliminate them? Clearly not! Medical science helps us to find the right routes of administration and dosages to minimize adverse effects. For example, many anti-cancer drugs are highly toxic. Nevertheless, these drugs have helped to save the lives of many patients.

Another example is the use of pesticides. These materials are toxic to agricultural pests, but if used carelessly at high concentrations they can also be harmful to people and the environment.

Discuss the pros and cons of using pesticides. Relate to the following points:
- Benefits of using pesticides?
- Hazards of using pesticides?
- How would the world look without the use of pesticides?
- Who would be the main victims of not using pesticides?

Toxicity and safety problems should be solved not by stopping the use of vital, irreplaceable materials, but by awareness of the hazards involved in their use and finding suitable solutions to minimize these dangers. Any handling, production or use of toxic materials must be under strict control and in compliance with safety rules, hygiene and protection of the environment.

Why is one material toxic and another not? What is the reason that certain halogen compounds are toxic and others less or not at all? These questions have
occupied the minds of many scientists for many years. Some of these questions have been answered; others are still shrouded in mystery.

Some people are convinced that the toxicity of the different halogen compounds depends on the size of the halogen atom or on its bonding strength.
- How do you think atomic size can influence bonding strength with other atoms? Discuss for example bonding with carbon atoms.
- Studies have proven that toxicity increases with increasing size of the halogen atom. Try to explain this.

Compounds containing C-F bonds are stable and do not react easily; the more C-F bonds they contain, the lower their toxicity. Chlorine compounds, such as CH₃Cl, CH₂Cl₂ and CHCl₃ that contain C-Cl bonds are known to be toxic. Similar bromine compounds containing C-Br bonds are even more toxic. Examples are CH₃Br and ethylene dibromide, CH₂BrCH₂Br, which are used as pesticides. Iodine compounds are even more toxic than bromine compounds, but because of iodine’s relatively rare occurrence they are much less used and more expensive than the other halogens.

The toxicity of bromine or chlorine compounds can be reduced by addition of fluorine atoms, which stabilize the C-Br and C-Cl bonds and therefore the whole molecule. If we compare CH₃Br, which is extremely toxic, with CF₃Br, we see that the latter is stable, non-toxic and used as fire extinguisher. Other examples are CFCs such as CHCIF₂ and CCl₂F₂, which are non-toxic and until recently used as refrigerants (air conditioners and refrigerators) and propellants. The stability of fluorine compounds has also a negative aspect. It is now known that extensive use of CFCs damages the atmospheric ozone layer. Since the stable CFC molecules accumulate in the atmosphere, they cause permanent damage to the ozone layer. Today the use of these materials is restricted or prohibited in many countries and suitable replacements are being sought.

Since the mid-1970s there is a growing, worldwide interest in health and environmental issues parallel with an increasing awareness of the problematic nature of toxic compounds. Many countries have introduced legislation and regulations on these subjects, which are now part and parcel of the licenses for use of toxic or hazardous materials.
**Registration:** Procedure to add a material to the list of materials approved by the registration authorities for manufacturing, marketing or use.

**Licensing:** Granting of permits by the authorities for a specified use of a toxic material.

The Dead Sea Bromine Group has established a special department to deal with toxicity, safety, health and environmental issues, which is responsible for the products during their entire life cycle: data are collected for each material at all stages of its development and use, including after its use has terminated and the product discarded. A team of experts has been set up specifically to classify materials and their properties, and to issue appropriate safety instructions for working with these materials. This in fact represents a comprehensive system of total product management.

**How do we learn about a new material?**

We start by reviewing the literature and registered patents. At a more advanced stage, after optimization of process and product, the material is tested in different laboratories around the world to get a picture of its biological and chemical properties. Laboratory tests are performed to find out if the material is very toxic, corrosive, mutagenic or carcinogenic. Long-term toxicity is also determined to evaluate the possible effects on employees after long-term exposure to small quantities of material. These tests are performed in compliance with internationally accepted standards.

Based on the data obtained, the material’s properties and safety level are determined and a profile is drawn up to establish safe working rules.

**Initial toxicity studies for new product development**

* Ingestion (Acute oral LD50)
* Inhalation
* Skin irritation
* Eye irritation
* Dermal sensitization
* Mutagenicity

The product will not begin the manufacturing stage before all available information on its properties has been collected, including detailed safety instructions to protect the employees and information on its environmental effects.

In the final stage, when the product leaves the plant on its way to the customer, several formal requirements concerning packaging, labeling, transport and product use must also be fulfilled.
The procedures required for approval of the company’s products are divided into two groups:
- Agricultural products (pesticides) and biocides (disinfectants)
- Products for industrial use

For biologically active pesticides and disinfectants a license is needed, while products for industrial use can be divided in two groups: registered and non-registered products. Registered products do not need a license and for non-registered products a licensing procedure is introduced until the product is approved for sale.

Safety and industrial hygiene issues include knowledge of the laws concerning safety in the workplace and consumer protection, and preparation of safety data sheets and emergency aid instructions. This department also specializes in international laws dealing with various environmental issues, such as regulations on transport and packaging, labeling and international marking. The safety data sheets contain much useful information for company employees and customers. The next page shows the information appearing on the safety data sheets.
Material Safety Data Sheets (MSDS)

<table>
<thead>
<tr>
<th>Product identification and manufacturer</th>
<th>Handling and storage instructions</th>
</tr>
</thead>
<tbody>
<tr>
<td>* Chemical name</td>
<td>* Routine handling</td>
</tr>
<tr>
<td>* Formula</td>
<td>* Storage</td>
</tr>
<tr>
<td>* CAS # (Chemical Abstract Number)</td>
<td>Chemical and physical properties</td>
</tr>
<tr>
<td>* Chemical class</td>
<td>* Appearance</td>
</tr>
<tr>
<td>* Molecular weight</td>
<td>* Melting point</td>
</tr>
<tr>
<td>* Type of material and use</td>
<td>* Boiling point</td>
</tr>
<tr>
<td>* Manufacturing company</td>
<td>* Vapor pressure</td>
</tr>
<tr>
<td>* Manufacturer’s address</td>
<td>* Partial gas pressure</td>
</tr>
<tr>
<td>* Emergency telephone</td>
<td>* Solubility</td>
</tr>
<tr>
<td>Component identification</td>
<td>* Density</td>
</tr>
<tr>
<td>* Hazardous components</td>
<td>* Thermal decomposition</td>
</tr>
<tr>
<td>* Other components</td>
<td></td>
</tr>
</tbody>
</table>

Main risks

* Main hazards
* Health hazards

Emergency aid

* Eye contact
* Skin contact
* Inhalation
* Swallowing

Treating fires

* Fire extinguishing procedure
* Flash point
* Ignition point
* Extinguishing media
* Flammable/explosive limits
* Fire fighting procedure
* Unusual (fire and explosion) hazards

Procedures in case of emission or spillage

* Personal precautions
* Handling of spillage/leakage

Personal protection/Exposure reduction

* Exposure limits
* Ventilation requirements
* Fire protection equipment
* Industrial hygiene rules

Stability and reactivity

* Stability
* Incompatible materials
* Hazardous conditions
* Hazardous decomposition products
* Hazardous polymerization

Toxicological data

* Toxicity data in laboratory animals
* Overexposure symptoms
* Chronic toxicity and carcinogenicity (on long-term exposure)
* Mutagenicity

Environmental data

* Toxicity to organisms living in the environment
* Chemical decomposition in the environment
* Biological decomposition in the environment
* Environmental effects (air, soil and water)
* Waste disposal recommendations

Transport

* Sea transport
* Air transport
* Land transport

Legislation and regulations

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10 Commonly known in Europe as Safety Data Sheets (SDS)
In 1991 a clinical toxicology unit supplying special services to the Dead Sea Bromine Group and other companies in the Negev, was opened in Soroka Hospital, Beer Sheva. The principal aim of the unit is to look after the employees’ health and at the same time to develop a toxicological center that will serve the heavily industrialized Negev region. Any new compound prepared in the company is investigated in the clinical toxicology unit. The unit performs comprehensive tests on the medical implications of employee exposure to raw materials, solvents, intermediate products and final products involved in the production process. It issues forms with recommended medical treatments to be used, if needed, by the plant medical team or the hospital. This saves much valuable time otherwise spent on the search for information on the materials and their effects on the employee.

One of the more important tasks of the clinical toxicology unit involves preventive medicine. This is put into practice by having each employee medically examined at least once a year. An additional task, and one which is no less important, is instructing the employees in the medical effects of the materials they work with, with the aim of increasing their understanding of the vital importance of observing the safety rules.

**Industrial Hygiene:** Keeping clean in order to prevent illness and disease  
**Occupational health:** Staying healthy in the workplace

In the Dead Sea Bromine Group, as in other advanced industries around the world, there is a tendency to replace hazard warnings with risks warnings. A material with known, even hazardous, properties may be used safely if the risks are known. Risk assessments models have been developed that are used to devise safety enhancing methods and tools. Today we speak less about toxicology and more about a holistic approach to the environment involving product management from the birth of the idea to the end of the product’s life cycle; from manufacturing problems to consumer questions about packaging, spent materials or waste products.

**Risks:** The possibility of suffering harm under certain conditions  
**Hazards:** Potential of material to cause damage under certain conditions  
**Safety:** Measures taken to reduce risks
4.5 - **Industrial waste treatment**

**General**

New legislation and joint action of the Ramat-Hovav local council and industrial enterprises led to the foundation of a common biological waste treatment plant for organic compounds. The plant is situated in the Ramat Hovav industrial area and operated by the local council. It reduces the amount of industrial organic waste and so lowers the risks involved in storing organic waste in open pools. All regional industries are obliged to make use of this facility, which saves money in addition to providing efficient and professional waste treatment. Before transferring the waste to the central facility, every plant has to carry out its own **pretreatment**. This is done to obtain a certain level of waste quality suitable for uniform biological treatment.

At Bromine Compounds Ltd. special equipment is used for physical and chemical pretreatment of waste, which includes the following steps:
- Homogenization of waste
- Neutralization of waste
- Compression and precipitation of heavy solids
- Precipitation of suspended solid particles
- Filtration

At Bromine Compounds Ltd. the approach is to isolate the problem: each unit treats its own waste, until it is ready to join the plant’s central waste system for further treatment (as detailed below).

At the end of the process diluted waste and sludge are obtained. According to the regulations, the sludge is removed to the industrial waste processing plant adjacent to Ramat Hovav for further treatment, followed by combustion. The diluted waste flows by gravitational force through a resistant plastic pipe that is protected against leakage to the biological treatment plant. The waste enters the plant via a device for removal of volatile organic components, which are the main causes of unpleasant odors. From there the waste is pumped to different places, dependent on type and treatment phase.

**Biological treatment**

The waste, which was pretreated in the plants where it was generated, is **first treated to remove volatile compounds**. This is done in a special container by
air stream. The air leaving the container and carrying the volatile organic matter then flows to the biological treatment containers and is subsequently used as an oxygen source for the same process. The fluid in the containers absorbs the volatile organic compounds, which join the rest of the biologically treated organic material. After removal of the volatile compounds the waste is transferred to an intermediate pool (equilibration pool) in which it is kept for 80 days before continuation of the treatment. During this period the excess solids suspended in the waste precipitate and the waste becomes homogeneous.

The biological treatment is an aerobic process, which takes place in containers that are continuously supplied with waste from the intermediate pool. The biological treatment plant consists of two huge containers (with a capacity of about 8000 m³) in which the processing takes place, in addition to laboratories, control rooms and an in-process control unit.

Biological treatment is based on a biochemical process in which specific bacteria use the aerobically digested organic matter as carbon source for their nutritional and reproductive needs. The process takes place in an aqueous environment rich in other nutrients such as nitrogen, phosphorus and micro-quantities of other elements at suitable conditions of pH and temperature.

The treated waste is next transferred to specially constructed, leakage-resistant evaporation pools. Desalination is planned for the future, so that it will be possible to recycle the water for industrial use. The remaining biological sludge is sun-dried and further treated. Plans have been made to develop a process for converting it to fertilizer.
As early as 1955, the company built a pilot plant, which is actually a scaled down version of the central biological processing plant, to ensure proper and uninterrupted treatment of the bromine compounds waste. In this experimental plant the effect of the biological treatment on the plant’s waste, which varies as a result of changes in production cycles, interruptions in existing production processes, introduction of new production processes and construction of new production plants, is continuously assessed. Also participating in this project are the Ben-Gurion university laboratories in Sde-Boker, where ongoing tests are performed on samples taken from the different stages of the experimental treatment.
The complete treatment of industrial waste is shown in the following scheme:

Biological treatment scheme for industrial waste
Concepts studied in Chapter 4

Catalyst:
Substance added to the reaction to increase the reaction rate.

Catalyst poisoning:
A decrease in catalyst efficiency due to absorption of substances or other factors to its surface area that interfere with its function.

Catalyst recovery:
Restoring the activity of the catalyst

Control systems:
Instruments, tools and procedures for the monitoring of important variables in industrial and other processes.

Free energy of activation:
The energy needed to bring the reactants to the transition state enabling product formation to take place.

Hazards:
Potential of material to cause damage under certain conditions.

Industrial Hygiene:
Conforming to industrial health regulations in order to prevent illness and disease.

Input:
Any economic factor included in the calculation of overall product cost.

Kinetic control:
Concerns reaction rates and determined by the value of the free energy change of activation at a given temperature.

Licensing:
Granting of permits by the authorities for a specified use of a toxic material.
**Occupational health:**
Staying healthy in the workplace.

**Output:**
Amount of product obtained per unit time.
Output can be measured per hour, day, week, month or year.
Output of commodities is usually measured in tons or hundreds of tons per year.

**Quality Assurance:**
Systematically planned set of procedures needed to ensure that a product and/or service meet quality standards that fully satisfy customers’ demands.

**Quality control:**
Test to assess whether product quality at the end of the production process meets specifications or whether the product should be rejected.

**Process control:**
An integral part of the routine and regular operation of any industrial plant used to check that all stages of the process are proceeding as planned.

**Registration:**
Procedure to add a material to the list of materials approved by the registration authorities for manufacturing, marketing or use.

**Risks:**
The possibility of suffering harm under certain conditions.

**Safety:**
Measures taken to reduce risks.

**Scaling up:**
Increasing the amounts and equipment size in the transition from laboratory synthesis to industrial production.
**Scaling up stages:**
- Laboratory experiment
- Bench scale
- Pilot plant
- Industrial plant

**Thermodynamic control:**
Concerns the spontaneity of the process and determined by the value of the change in free energy of the process at a given temperature.

**Toxicology:**
Science dealing with the toxicity of substances for humans, plants and animals. Toxicology is an interdisciplinary science covering chemistry, biological systems and also physiological and biochemical processes in animals and in the human body.

**Workup:**
Series of procedures performed after termination of the reaction designed to obtain the highest amount of product at the necessary degree of purity.
Questions about Chapter 4

Chapter 4 deals mainly with general industrial concepts and principles, which can be applied to the bromine production process discussed in Chapter 3, and also to the different materials and production processes that will be discussed in the following chapters.

1. In Chapter 3 you learned that one way to produce chlorine is by electrolysis of a solution of sodium chloride. Use standard reduction potentials of the reactions for hydrogen, chlorine and oxygen formation and indicate if electrolysis is controlled thermodynamically or kinetically.

2. Develop a list of questions to which the operation of a pilot plant can provide the answers.

3. a. Consider the different stages of the bromine production process and give examples or suggestions how to save on inputs: water, energy and auxiliary materials.
   b. Protection of the environment relates to: air; soil; water. Give examples of potential sources of pollution of each of these environmental components for the bromine production process.
   c. What precautions are taken at each stage to protect health and environment?
   d. What if any other precautions should be taken? Please explain.

4. a. Which economic factors could influence the decision of a country to produce or import bromine?
   b. Which factors might influence bromine prices in the world?
   c. Which factors might influence the price of bromine compounds in the world?

5. Consider industrial processes in general and answer the following questions:
   a. What are the factors that determine the success of a production plant?
   b. What is the function of marketing in a production plant?
   c. Suggest ways that production plants could be improved, to become more efficient and to be more successful.
6. The proper functioning of a plant is to a large extent determined by quality control of the product.
   a. How is this quality control performed in the plant?
   b. What is the difference between quality control and quality assurance?
   c. Try to evaluate the advantages and disadvantages of each of the methods outlined in b. above. Would a single method be enough?
   d. What are the advantages of the environmental management system adopted by Bromine Compounds Ltd.

7. Table No. 4.1 on Page 143 gives examples of a number of toxic materials produced by the Dead Sea Bromine Group.
   a. What problems are caused by working with toxic materials?
   b. How are these problems solved?
   c. Give examples of safety measures taken by the industry when working with toxic compounds.

8. Industrial waste is a global problem. In recent years there is a growing awareness of the need to correctly handle industrial waste.
   a. A developed country is, among other things, judged by the way it takes care of its hazardous waste. Explain.
   b. How can we improve the way industries handle their waste problems?
   c. Which methods do you know for taking care of industrial waste? Explain.

9. Bromine can be used to generate hydrogen bromide. To do this, bromine is evaporated and made to react with hydrogen. The following are the equilibrium constants of the reaction at two different temperatures.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Equilibrium constant</th>
</tr>
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<tbody>
<tr>
<td>25</td>
<td>$1.3 \times 10^{19}$</td>
</tr>
<tr>
<td>500</td>
<td>$1.0 \times 10^8$</td>
</tr>
</tbody>
</table>

   a. Write down the reaction equation between bromine and hydrogen.
   b. Is this a spontaneous reaction at room temperature? Explain.
      Industrially this reaction is carried out at a temperature of 500°C and a
pressure of 1 atmosphere.

c. Calculate the reaction enthalpy
d. Explain why the reaction is carried out at 500°C and not at room temperature.
e. Explain why the reaction is carried out at a pressure of 1 atmosphere and not at higher pressure.
f. Which factors must be taken into account for the selection of construction materials for the reaction container?

10. Hydrogen bromide is usually marketed as an aqueous solution of HBr$_{[aq]}$.
For most purposes highly purified hydrogen bromide solutions are required. Such a solution is obtained by dissolving the gaseous hydrogen bromide formed by the reaction between bromine and hydrogen (see Reaction 1 on Page 14) in water.

a. Show in a simple flowchart the steps needed to obtain a pure hydrogen bromide solution from bromine and hydrogen. Describe each step.
b. Compare your suggested flowchart with that of other pupils and try to find the cheapest and most efficient way to generate a hydrogen bromide solution of the required purity. Detail the arguments used for the comparison.
c. Compare the different suggestions based on considerations such as:
   - Number of process stages
   - Conversion percentage
   - Reaction yield
   - Degree of product purity
   - Energy costs
d. What do you think is the recommended process? Explain your answer.
e. Which factors should be taken into account in the choice of construction materials for storage tanks of a hydrogen bromide solution?