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Preliminary Design of a Polyurethane Recycle Plant

Lay-out, PID, Safety, Availability, Maintenance, Costs and Environment

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Equipment for Process Industry
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PREFACE

This report is a part of the preliminary design of the Poly Urethane recycling plant. It deals with the relevant aspects of St 44, a course given at the Delft University of Technology. The main part of this report consists of the cost calculation of the plant. Unfortunately the results of the calculations in this report only provide a rough indication of the real investment costs.

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SUMMARY

This part of the report starts with the piping and instrumentation diagram as well as the layout. Complete determination on this part was not possible at this preliminary stage. As far as safety is concerned, a summary can be given on the harmful substances which this process contains:
- MEG vapour (explosive when contacted with air)
- DADPM (cancer inducing)
- HCl (special care should be taken)

The cost engineering yields the following results:
- Total Investment: Hfl 11,550,000
- Total Costs: Hfl 1.56 / kg PU
- ROI: 67% (7 yr. shorter than expected)
- Pay Out Time: 0.6 yr.
- IRR: 0.6%

On the environmental issue, the following can be said; the PU-recycling plant doesn't differ much from any other modern chemical plant. The environmental pollution can be reduced by a good treatment of wastes from the overall plant. All in all, this plant at this stage of the design is found to be feasible and profitable.
1 INTRODUCTION

The polyurethanes are all around us, playing a vital role in many industries, from shipbuilding to footwear, construction of cars. They appear in an astonishing variety of forms, a variety that is continuously increasing.

Rigid polyurethane foam is one of the most effective practical thermal insulation materials, used in applications ranging from buildings to the modest refrigerator. Comfortable and durable mattresses and car and domestic seating are manufactured from flexible foam. Items such as shoe soles, sports equipment, car bumpers.

At the moment waste polyurethane is burned, or dumped on garbage belts. Because of a change of attitude towards environmental issues the recycling of waste material has to be done by its manufacturer.

That’s why ICI is interested in designing a process for chemical polyurethane recycling.

In this report, lay-out and PID, safety and availability of the plant are described in the first three chapters. And next the maintenance, costs and the environment.
2 PIPING & INSTRUMENTATION DIAGRAM AND LAY-OUT

2.1 Introduction

For operation and safety of a plant, the control system is essential. A start of the design of a control system for the plant has been made. The resulting control loops and control valves have been drawn in appendix 2.1. This figure can be seen as start to make a piping and instrumentation diagram (PID), it is in fact a PFD with control loops and some instrumentation. When referring to the PID one has to keep this in mind. Some corrections with respect to the PFD in the report have been made. They are summarized at the end of this chapter.

In this chapter also a general layout of the plant is made. Special attention is paid to a compact but accessible layout of the plant.
2.2 General aspects of the PID

In the PID control loops and some additional valves have been drawn. The control is discussed later on. As far as the valves are concerned the following is drawn:

1. a 'no return valve' after each pump,
2. two valves at each side of a pump, so it can be taken out of the plant for maintenance,
3. two valves at each side of the filters between the reactors, so they can be taken out for cleaning.

Configurations to avoid cavitation are also drawn.

Items not drawn, but that usually do occur on a PID are: pipe diameters, reducers and expanders, all heat exchanger shells, spare pumps, more detailed plots of the unit operations, etc. Due to lack of time these items are omitted.
2.3 Process and Control loops

2.3.1 Introduction

To determine the necessary control loops in the plant, the dynamics of the process must be known. In this stage only qualitative knowledge of the process is used. The feed section and the ion-exchanger operate discontinuously, the reactor and ramming separation units operate continuously.

Only simple control loops have been designed. As usual, this chapter has been split up in feed, reaction and work-up section. For better understanding of the process a short summary is given. The codes for units are shown in the PID, they are the same as in the PFD.

2.3.2 The Feed Section

2.3.2.1 Process

Mixing and cutting PU

The feed mixture is prepared in V4. Every hour an hours feed for the plant is made. First the PU has to be cut. The cutters have their own control system, it is not discussed here. The discontinuous operation of this section is summarised as follows:

1. filling V4 with sufficient MEG and KAc simultaneously in 7.5 minutes,
2. adding the PU in 40 minutes and high shear mixing at the same time,
3. 5 minutes of extra high shear mixing,
4. pumping the prepared feed to storage vessel 6 (V6) in 7.5 minutes with the high shear mixer (HSM).

The HSM has no function for 7.5 minutes per hour. Because it is inefficient to stop it for this short time it should operate continuously. Because some resistance is required it will pump around MEG during the 7.5 minutes that V4 is being filled with MEG.

The mixture is pumped to flash vessel T1 continuously. In T1 the mixture is dehydrated at 0.10 bar. The vapour resulting from the flash contains MEG and H2O. This is condensed and stripped with N2. The N2, with water is led over a molecular-sieve bed, and recycled to the stripper. All MEG leaves the bottom of the stripper.

2.3.2.2 Control

The cycle time of the feed section is one hour. The control could be fully automatic, but manual operation can be easy, and cheaper. Manual operation means that the operator of the plant pushes several buttons in the control room when this is required.
The amount of material in V4 is determined by weighing ('mass control', MC).

A schematic overview of the actions to be taken is given. The reader is referred to appendix 2.1. for the 'PID'. We start with an empty V4, the valve in the recycle loop from HSM, and from V4 to HSM have just been opened, and the valve in the pipe to V6 has just been closed.

1. A sign is given in the control room, indicating that the preparation of a new batch of feed has to be started. By manual control the following actions are taken,
2. The valve between V2 and the mixing point, and between P1 and V4 are opened. P1 is started and pumps MEG to V4. In the mean while the HSM is pumping the fed MEG around.
3. The dosing pump is started and pumps the required amount of KAc/MEG to V4, this is done in about 5 minutes.
4. The mass of the vessel plus contents is weighed continuously. When the required amount of MEG is present (after about 7.5 minutes), the mass controller sends a signal closing down P1 and the valves between storage vessels and V4.
5. The conveyer belt starts feeding PU to V4. The HSM is still pumping around MEG, and now also PU, tearing the PU apart.
6. The mass controller sends a signal to the belt stopping it, when the required amount of PU is fed, this takes about 40 minutes.
7. After an additional 5 minutes of mixing the valve to V5 must be opened first, the valve in the recycle pipe to V4 must be closed. V4 is emptied, and V5 is filled.
8. As soon as the mass controller determines that V4 is empty, the valve in the recycle pipe is opened, and the valve to V5 is closed.

Transporting PU to the flash vessel

After V6, the process is continuous. A constant flow must be pumped from V6. The flow is sampled before entering H1. The flow is controlled by a valve. The valve is placed near the flash vessel T1, so the pressure of the stream drops. The operation pressure of T1 is 0.10 bar.

Flashing the mixture

The temperature of the flash feed must be 150°C. As it is heated by the MEG recycle from the distillation, temperature control can be accomplished by controlling a by-pass of the hot stream to the exchanger.

H1 has been designed by passing all the hot stream through the exchanger. The minimum temperature difference of 10 °C was used in design. The highest attainable temperature for the flash feed is 150°C. This means that no control is possible if the flash feed is to cold. This problem can be solved by designing a larger H1, and by-passing some hot stream under normal conditions. If the flash feed is to cold for some reason, the fraction by-passed can be reduced. If the flash feed is to hot, a larger
fraction of the hot stream than normal can be by-passed. Note that if the new 'larger' exchanger has to correct for a too cold flash feed, the minimum temperature difference in the exchanger will be smaller than 10°C.

The flash pressure is 0.10 bar. This pressure is maintained by condensation of the MEG/H$_2$O vapour. Because some air will leak into the vessel it is necessary to place a small vacuum pump at the an outlet of the condenser. This system is shown in the PID (appendix 2.1). To make sure the pressure will not become to low, the pressure in the vapour line is measured, and air can pass through the control valve. If the pressure is too high, some MEG/H$_2$O is sucked away.

The temperature in the condenser is controlled by measuring the temperature of the condensate, and correcting by controlling the flow of cooling water.

Because the condenser does not sub-cool the vapour, fluctuations in pressure can cause vaporisation. There is thus a risk of cavitation in pump P3. The condensate from the condenser is fed to a small vessel, with a certain liquid level in it. The level is controlled by the flow a the discharge side of the condensate pump, which pumps the condensate to stripper T2. This pump is placed under this vessel. With this configuration the risk of cavitation in the condensate pump is reduced.

No attention has been paid to the nitrogen dryers here because they have not been treated in the main report. Control will be needed to change the used dryers. A dryer will be saturated at some time, and it will have to be regenerated.

In the flash vessel a certain liquid level must be maintained to avoid cavitation in the flash bottom pump. Again the level is measured and the flow at the discharge side of the pump is controlled.

2.3.3 The Reactor Section

2.3.3.1 The process

In the reactor section the PU is converted in two reactors with a filter in between. CO$_2$ is released and this must be vented. The two phase liquid product stream is separated in a settler. The bottom phase is distilled, the heavy component, rigids, is bottom product. Top product is MEG, containing some DADPM.

2.3.3.2 Control

Reactor

The reactor feed is heated by H4 before entering the reactor. The reactor temperature is controlled by the hot stream flow to H4, as the reactors are only isolated in the design so far: no heat can be supplied or withdrawn from the reactors. Because the residence time is about 2 hours in the reactors an adjustment of the feed temperature does not have a rapid effect. This calls for heating/cooling directly in the reactor. On
figure 2.1: syphon for settler control
the other hand disturbances due to incorrect feed temperature do not have a rapid effect either.

The reactor pressures are controlled by venting the vapour if pressure gets to high. Pressure drop to 1 atmosphere can be accomplished through pressure drop across the control valve in the pipe to H5.

Condenser H5 condenses the MEG in the vapour from the reactor. Condensed vapour is assumed to flow back into R2. To make sure all MEG is condensed and only CO₂ is vented, the temperature of the cooled (vapour) stream must be controlled.

Because of contamination of the filter in between R1 and R2 it has to be cleaned. It is assumed that this does not occur frequently, so manual cleaning is possible. The contamination of the filter is determined by measuring the pressure drop across the filter. If a certain pressure drop is reached, this is made known in the control room. Manually or automatically the valves can be switched, so the reactor effluent passes through the clean filter. In the meanwhile the contaminated filter is cleaned.

The level in the reactors must be controlled to avoid flooding. The level in R1 is controlled by the flow to the second reactor. Simultaneously the flow to R2 is controlled: if a certain level in the R1 is assured, there must be a certain effluent flow. The level, and thus the effluent flow, of R2 are controlled by a simple control valve in the effluent pipe. The pressure drops from 3 to about 2 bar.

Settler

The operation of the settler can be controlled by a syphon, shown in Figure 2.1. It is very important that no light or heavy phase passes through the wrong exit, therefore the settler must be designed safely. There are two kinds of disturbances possible: a different light/heavy phase feed of the settler, and a reactor effluent containing no flexibles and rigidis, if the feed section fails.

A settler with a syphon has the function of a buffer. Even though fluctuations in the fed heavy and light phase are not expected, as PU has a constant composition, they can be suppressed to some extent in the settler.

If no PU were in the reactor feed, there is only MEG fed to the settler. As the heavy phase is MEG for a great deal, MEG can both pass through top and bottom exit. The hydrostatic pressure in the syphon is not higher than in the vessel, as it is when there is a light and a heavy phase, so there is no danger that no stream goes to the distillation T3.

Distillation

The control system for the distillation T3 has been taken from Coulson [1]. The reflux ratio is controlled by a ratio controller. The bottom product is a fixed ratio of the feed flow.

Also here cavitation is prevented by a certain level of liquid in a vessel above pump P8. This is necessary because the condensate is at it’s boiling temperature, and even a slight decrease of pressure can cause vaporisation.
figure 2.2: control system for vaporiser (heater)
2.3.4 The Work-up section

2.3.4.1 The process

The work up consists of an extractor for DADPM removal from the settler's top stream, a flash to remove the MEG (top product) from the flexibles (bottom product), and an ion-exchanger to remove the remaining DADPM from the flexibles. Extractor and flash operate continuously. The ion exchanger has two columns parallel, operated one at the time. After a day, the column in operation is changed, and the previous operating column is regenerated.

2.3.4.2 Control

Extractor

The operation temperature of the extractor T6 is critical, a higher temperature worsens the stripping factor. It is therefore essential that the temperature of the feed streams is measured, and the cooling water stream to H8 and H9 are adjusted.

To assure a constant stripping factor in T6, the two feed streams are kept in a constant ratio.

The temperature and pressure in the extractor are such there is no danger of vaporisation and thus no danger of cavitation in pumps P10 and P11.

Flash T7

The flash feed must be heated to 198°C and vaporised. The operation pressure is 1 bar, so MEG boils at 198°C. The fraction of feed vaporised can be controlled by level control see Figure 2.2 taken from Coulson [1]. If the liquid level is held at a certain value, this means that a certain fraction of the feed is vaporised. If the liquid level is too high, the amount of hot steam is increased.

The low pressure in the flash is controlled like the flash in the feed section. Because the vapour is cooled far below it's boiling point to 80°C, a vessel with a liquid level (as in the feed sections condenser) is not strictly necessary.

The bottom product is mainly flexibles. These are so heavy that they will not boil at all at 198°C. So a level control in the flash T7 to avoid cavitation in pump P12 is not strictly necessary.

Ion-exchangers T8 and T9

Above a temperature of 120°C, the packing of T8 and T9 degenerates. For that reason a control of H14's operation (again by adjusting the cooling water stream) is essential.

A signal to change of operating column is given in the control room. By hand the pipe to the used exchanger is shut off, and simultaneously the pipe to the flash column is opened. The previously used column is emptied, and the flexibles/MEG are sucked though the fresh column. As soon as the contaminated column is empty this is measured by a level controller. Then the regeneration of the column can start. The valves between regeneration fluid vessels and column are opened. After cleaning with
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liquid, these valves are closed and the valve in the hot air supply pipe is opened by hand. After drying it is closed by hand.

2.4 Corrections with respect to the PFD.

Except from adding valves and loops some corrections have been made:

1. vacuum pumps have been added in the feed section (for the flash) and for the flash in the work up section,
2. P4, as in the PFD has now been drawn as a compressor instead of a pump,
3. a pump has been placed in stream 16 (P5a), to boost pressure from 0.10 to 5 bar, and a pump (P5b) has been placed in stream 15 to boost pressure from 1 bar to 5 bar,
4. demisters have been drawn in the flash vessels.
Figure 2.3: Layout scheme
2.5 Plant Layout

Although the preliminary design of the PU recycling plant has been made in order of ICI Rozenburg the possible location of the plant does not necessarily have to be there. For instance the infrastructural location of the ICI Rozenburg plant is very good but it is also rather expensive. It is however not in the scope of this report to carry out an investigation to the optimum plant location. Here is dealt with a few aspects concerning general plant layout. The following assumptions have been made:

- The plant is a grass-roots plant.
- As site services are present; electricity, steam, cooling water, N\textsubscript{2} and HCl.
- The piece of soil on which the plant shall be built has a rectangular shape.

2.5.1 General Layout

Two methods for plant layout can be used [3]:

- The flow-line pattern in which the equipment is arranged according to the process flow.
- The grouped (or functional) pattern in which equipment of similar function is grouped together.

The flow-line pattern is used for the layout of the PU recycling plant, except for the storage tanks which are placed together in a tank farm. Therefore the division in feed, reaction and work-up sections as used all through the preliminary design can be found back in the layout of the plant (See Figure 2.3). The reasons for the use of the flow-line pattern are:

- The reduction of piping to a minimum. Almost all equipment works at elevated temperatures. Therefore the piping between the equipment has to be insulated. Insulated piping is rather expensive.
- The use of different kinds of equipment. Because in the design only a few identical types of equipment are used it is overdone to group these together.
- The limited size of the plant.
- Maintenance of a clear overall view over the process flow.

In Figure 2.4 & 2.5 the possible layout of the plant is printed. The equipment is installed from 'tall' to 'short'. The shorter equipment is installed directly opposite of the tank farm, the taller equipment further away. This is done because during construction or shut-down (maintenance) space is necessary to handle the equipment. It is easier to handle the tall equipment without being limited in space by the tank farm. The width of the service road between tank farm and plant is 6 m. On a whole is looked at a compact design. Spacing between the equipment is approximately 1.5 m. Generally the equipment is placed hanging between the two levels of the construction. Hereby is aimed at optimum accessibility of the top of vessels. Nowhere in the plant a vessel elevates more than 1.5 meter above the floor of the level. This to facilitate inspection of the interior of the equipment by personnel. The control room is constructed close to the entrance of the plant and in sight of the loading points of the tank farm and the cutter building. Distance from the plant is at least 10 m.
The plant has an open structure except for the part where the intake and cutting of crude PU takes place. In this part of the plant the structure has to be closed to prevent rain from wetting the PU and to protect the moisture sensitive cutters. After cutter 2 the PU is blown through a closed pipe to V5 which can be installed outside again. Advantages of an open structure over a closed structure are:

- Reduction of explosion hazard.
- Installation of and access to equipment is easy.
- Maintenance is relatively easy.
- Flexibility of structure is good.

2.5.2 The Tank Farm

As can be seen in the PFD (Appendix A4.III [2]) storage tanks V1, V2, V3 and V6 contain MEG. Tanks V8 and V9 contain HCl. Both substances are hazardous for the environment. In case of leakage of the storage tanks it has to be avoided that these substances contaminate the environment. Therefore all storage tanks are placed together in a bund with a common wall (See Figure 2.5). The basin shall be made out of impermeable concrete and be equipped with an appropriate drainage and fire extinguisher system.

2.5.3 The Oil Heater

A few heat exchangers in the plant use oil as heating agent because the temperature of the high pressure steam is not high enough for the required heating service. The oil is heated to the appropriate temperature in a furnace. Therefore the heater has to be placed approximately 15 meters away from the plant. This to reduce the ignition and explosion hazard in case of leakage of MEG to the atmosphere.

2.5.4 The Piping

All piping is installed above the surface except for the piping from and to the tank farm. This part of the piping crosses the main service road of the plant and is therefore installed under the surface. As said earlier almost all piping has to be insulated to prevent heat loss due to convection and radiation. It is also necessary to install expansion loops in the piping. This to avoid buckling of pipes due to thermal expansion.

2.5.5 Cutter Loading Zone

At this point it is not clear with what frequency trucks with crude PU will be unloaded at the plant. It is therefore hard to design a storage for the crude PU. Problems that have to be dealt with are:

- The storage has to be 'rain-proof'.
- A labour extensive way to unload the trucks and load cutter 1 has to be found.
Figure 2.5: Cross-sectional view and top view over tank farm
With the second problem mentioned the solution largely depends on the type of truck which is used and the shape of the crude PU. One can think of an elevated unloading platform from which the crude PU is dumped into a hopper on top of cutter 1.
Literature

3 SAFETY

In order to protect people and environment against sudden occurrences that give rise to
dangerous situations, safety is the most important aspect in designing and operating a
factory. Therefore great effort has to be taken to make a factory as safe as possible.
Until now a wide variety of methods exists to describe and to diminish the potential
occurrence of events that can lead to accidents within the factory. The method that will
be used depends on the philosophy of the company. Therefore it is not useful to
describe a specific method of "safety"-analyses. In this part the general rules and
guidelines are written down. It goes without saying that for the actual "safety"-analyses
the advice of experts is needed.

3.1 General Aspects

In order to define safety the following can be applied:

"Safety is a condition, in which the risk has a certain boundary value."

As a guideline towards safety-aspects there exist two important laws. These are the
"Steam-law" and the "Labour-incapacity-law".

Steam-law

This law applies for apparatus that generate or use steam. Approval of the design as
well as periodic control of these apparatus are required. Although apparatus that operate
under pressure without using steam are officially not covered by this law, in practice
the manufacturers apply the same law on these apparatus.

Labour-incapacity-law

This law basically incorporates the safety, health and well-being of the employees. This
law only gives a general guideline; detailed prescriptions will be given by the board of
management.

3.2 System Analyses

In system-analyses the behaviour of the process is investigated by process-parameters
like pressure, temperature, nature of substances, concentrations and construction-
materials. This procedure analyses the properties of hazardous process-substances and
the influence of these substances on environment and on themselves. The influence of
the environment on the process-substances is also taken into account.
In order to perform a system-analyses "Flowsheeting for safety" is used. For the potential hazardous substances used in this process like DADPM, MEG and KAc tables occur as mentioned in Appendix 3.1. Because cutting the polyurethane-foam leads to small particles, dust-explosion has to be taken into account. However dust-explosion generally occurs if the diameter of the particles is less than 100 μm. In this case the average diameter of the PU-particles formed is about 0.1 mm. This doesn’t mean that no particles with a diameter smaller than 100 μm are formed, but the concentration of these particles gives no rise to dust-explosions.

3.3 Disturbance Analyses

In order to find deviations that can lead to potential danger in the process, disturbance-analyses has to be done. A definition of disturbance-analyses is:

"Disturbance-analyses is a systematic inquiry into all predictable deviations of a normal process-behaviour (including start-up and shut-down), into qualitative descriptions of causes and effects of deviations, and into essential actions."

A disturbance-analyses not only deals with safety, but also with a good company-management. Generally disturbance-analyses is done by a number of people. A part of this group has to be occupied by actual labourers in the future factory. The outcome of disturbance-analyses may not be influenced by financial aspects. This procedure leads to a final report in which comment on the following points is absolutely necessary:

- Less common questions and arguments and decisions in relation with those questions and arguments;
- Suggestions for technical or technological improvements of the preliminary process-design;
- Recommendations for a special procedure that has to be followed in case of incidental occurring process-situations like for example shut-down.

One way of doing this analyses is using a checklist (appendix 3.II).

3.4 Actions and Measures

As a result of the "safety"-analyses actions and measures can be taken to decrease the risk. These actions and measures can be divided in 4 main-phases:

1. Process-technological improvements like diminishing the hold-up, avoiding flange-connections, screwed-connections, avoiding vibrations, etc.
2. Avoiding the occurrence by an active control system. For example by control equipment or parallel disposition like independent energy-supply by both steam and electricity.
3. Actions after the occurrence. For example using spare pumps, detection-systems, alarm-systems, etc.
4. Secondary degree hazards. Here the surrounding has to be protected against pressure, radiation, etc. Practically this has to do with lay-out, tankholes, fire-extinguishing-systems, etc.

3.5 Prevention During Operation

Although the utmost attention is paid to safety-aspects during the design of the plant, it is essential to make sure that safety is provided during operation. Therefore the following points need attention:
- observation of prescriptions
- regular inspection of hardware like instrumentation-systems
- good education of operators
- instructions for the control of the process and what to do if process-deviations occur
- sparkles tools and shoes
- no flammable materials like wood in or around the installation
- well-trained firemen
- emergency plan
- means of communication
- maintenance and inspection
- vibration-analyses

3.6 Protection by Apparatus

To prevent the occurrence of a critical situation as a result of an abnormal condition the equipment itself can be used as a defending line. This can be done by direct interference like opening a valve or by indirect interference like giving an alarm. It should be stated that control-systems do not belong to this group, because they have an active function like maintaining the normal conditions. Most of the preventions are of mechanical nature like shearing pins, slip-action clutches, jaw plates and safety valves. These mechanical preventions can be used separately or in series in such a way that at least one of them is active. Generally the safety valves are designed on the highest possible flow. In appendix 3.III gives some examples of systems in which a safety valve is needed.
3.7 Vent Systems

In most processes vent-systems are needed. Part of these systems operate continuously. Another part operates discontinuously at expected and unexpected moments. As most common gas vent-systems flares and chimney stacks are used. In case a flare is not operative, a small gas-stream has to make sure that no air from outside can invade the system.

The use of vent-systems during unexpected circumstances is of great importance for the security the entire process. Examples are:

- venting during an emergency stop
- venting small amounts of gas in case unexpected situation occurs

An emergency stop can be the result of for example a power breakdown. Because of safety-considerations not critical flammable gases can be vented on the flare-system, whereas dangerous or inflammable gases have to be vented far above a place that can be reached by human-beings. Generally stop- and start pipes are used by an emergency stop. If this is not sufficient additional supplies are needed.

3.8 Fire Protection

There are 4 important methods to extinguish a fire:

1. Disconnection of the fuel stream towards the fire. This can for example be done by pumping the fuel to empty storage-vessels. This method implies that during the process-design phase valves have to placed on easy reachable spots.
2. Disconnection of air/oxygen supply towards the fire. The same means as method 1 can be used.
3. Cooling down beneath the ignition-temperature. This means that the heat-production is smaller than the heat-outflow. Water can be used to establish this situation.
4. Change ment of the fuel/oxygen ratio. This is mainly done by dilution of air with for example CO₂

The working of fire-extinguishing agents is strongly related to this 4 methods. Foam- and emulsion-forming agents work according to 1 and 2 by formation of a two-dimensional layer.
Powders are fast working solid fire-extinguishing agents. They extinguish the fire by changing the fuel/oxygen ratio. Besides changing the ratio these agents also give rise to endothermic reactions with the result that the heat-outflow is bigger than the heat-production.
3.9 General Considerations

In order to establish a "safe" process care must be taken not to overdo it. This means that a too complicated safety-system gives rise to insecurity. It is for example possible that certain safety-loops overrule other safety-loops which can result in a disorderly situation. Therefore it is recommendable to create a safety-system that is easy to understand and to survey. Improving the survey can be done by using codes like numbers and different colours for pipelines, storage-vessels, etc. Appendix 3.IV gives a possible way to use codes.
4 AVAILABILITY AND RELIABILITY

The availability is the number of days per year that an installation operates. The reliability of an installation is the probability that this installation operates a certain time and under certain circumstances [4.1]. The reliability and availability of an installation are strongly related to the safety. An increase in safety implies an increase in reliability. A quantitative description of availability and reliability is feasible but complicated. A quantitative description in this case is beyond the scope of this project. The knowledge of experts is definitely needed. A qualitative description of events that can give rise to calamities can be divided in internal causes and external causes. Examples of internal causes are:

- operational errors like incorrect start-up, shut-down, etc.
- incorrect inspection, maintenance or reparation.
- deviation of tied-up procedures
- contamination and blockage
- exhaust of packing and seals
- corrosion and erosion
- mechanical strain
- thermal expansion
- internal explosions

Examples of external causes are:

- influences of weather like wind, lightning, temperature
- inundation
- soil-sagging
- explosion or fire in the environment
- disturbances in the fuel supply
- design, construction or assembly errors
FIGURE 5.1
5 MAINTENANCE

It goes without saying that safety, availability and reliability are strongly related to maintenance. The general conception "maintenance" can be divided in two mayor types namely:

1. Preventative maintenance
2. Corrective maintenance

Preventative maintenance is done before a disturbance occurs and corrective maintenance is done after the occurrence of a disturbance. Figure 5.1 illustrates this distinction. Once the condition-decline of the system is known periodic maintenance is feasible. This results in periodic revision, periodic change of components and periodic operational maintenance.

The goal of revision is to bring back the system to the level of it's original performance. A disadvantage of revision is a higher degree of disturbance due to inevitable assembly errors.

Through changing components a better view upon the disturbance behaviour of the components can be achieved. Disadvantages are that additional investment costs are required and that the part of the process have to be shut down.

Operational maintenance incorporates cleaning, oiling, etc. The goal of operational maintenance is to decrease the condition decline.

If the condition decline of the system is unknown measurements are needed to determine the state of condition. This can be done by inspection and condition guard.

Inspection incorporates the determination of the condition of the system during operation and during shut-down by partial dismantle.

Condition guard incorporates the measurement of properties that indicates the condition of the system during operation.

In order to provide good maintenance an organisation have to be created. This organisation will operate according a maintenance draft. An example of a maintenance draft is given in appendix 5.1. The first maintenance draft is created during the design and development stage of the system. Because the designer doesn't know the actual disturbance behaviour of the system, the first maintenance draft will be overdone. Creation of a good maintenance draft is only possible if the actual disturbance behaviour is measured. Because the disturbance behaviour differs in time, the maintenance draft changes continuously.

It goes without saying that the maintenance draft has a great influence on the reliability and the costs. Figure 5.1 shows how the failure rate (\( \lambda \)) and maintenance costs are related.
If preventative maintenance is compared with corrective maintenance regarding the costs, preventative maintenance is often favourable. Nevertheless care has to be taken to provide a strong increase in costs because of the extra material needed. The problem is that creating a maintenance draft based on preventative maintenance is a difficult and long procedure. Besides, it is difficult to prove the efficiency of preventative maintenance on forehand.
Figure 6.1A Cost build-up scheme

Enige in de literatuur voorkomende totale kostenmodellen, exclusief rente en afschrijving. Dit is in de *gewallen wel inbegrepen.
Zie voor de grootte van dit verschil IV-2.2.5.

\[ K_T = aK_P + bK_L + f1 \]

<table>
<thead>
<tr>
<th>Auteur</th>
<th>a</th>
<th>d</th>
<th>f</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clarke</td>
<td>1,0</td>
<td>2,3</td>
<td>0,1</td>
</tr>
<tr>
<td>Aries</td>
<td>1,33</td>
<td>2,43</td>
<td>0,106</td>
</tr>
<tr>
<td>Peters</td>
<td>1,138</td>
<td>2,83</td>
<td>0,17</td>
</tr>
<tr>
<td>Holland/Watson</td>
<td>1,033</td>
<td>2,58</td>
<td>0,096</td>
</tr>
<tr>
<td>Wells</td>
<td>1,0</td>
<td>1,25</td>
<td>0,13</td>
</tr>
<tr>
<td>Bridgewater</td>
<td>1,2</td>
<td>2,54</td>
<td>0,17</td>
</tr>
<tr>
<td>Isard</td>
<td>1,0</td>
<td>1,93</td>
<td>0,194</td>
</tr>
<tr>
<td>Jelen</td>
<td>1,12</td>
<td>2,34</td>
<td>0,294</td>
</tr>
<tr>
<td>&quot;Beste model&quot;</td>
<td>1,13</td>
<td>2,6</td>
<td>0,13</td>
</tr>
</tbody>
</table>

1) Bridgewater, I.Ch.Eng. Symposium Series 45

Figure 6.1B Coefficients for simplified cost model
6 COST ENGINEERING

6.1 Introduction

To get a good estimation of total cost of this process all the possible costs have be taken into account. In Figure 6.1 a graphical representation of all the kinds of costs which have to be made to operate this process. According to Montfoort [2] the costs for a chemical product can be calculated with following equation.

\[ K_T = K_A + K_P = K_A + K_O + K_P + K_I + K_L \]

where

- \( K_T \) = total costs.
- \( K_A \) = general costs.
- \( K_P \) = production costs.
- \( K_O \) = costs for plant overhead.
- \( K_P \) = total variable or production-dependent costs.
- \( K_I \) = total investments costs.
- \( K_L \) = costs of labour "semi-variable" costs.

Calculation of the total costs in this way is only possible when all the costs are known. In this stage of the process design it is advisable to use the simplified model given in Montfoort. In this model are the \( K_A \) and the \( K_A \) put into a new \( K_I \) and \( K_L \). The simplified model becomes:

\[ K_T = K_P + K_I' + K_L' \]

According to Montfoort [2] the \( K_P \) has specific factor \( a \). The semi variable costs \( K_L' \) are calculated from the labour costs \( L \) multiplied by a factor \( d \). And the \( K_I' \) by multiplying the total investment \( I \) by the factor \( f \). All these factors are given in Figure 6.1b according to different authors. The new equation for \( K_T \) becomes:

\[ K_T = a * K_P + f * I + d * L \]

In this report is the factors used which are given by the heading "Best Model". When this factor \( f \) is used the interest and the depreciation of the investment costs are not taken in account. These will be calculated separately.
6.2 Investments

Before a decision based on certain economic criterium can be made concerning whether or not to proceed through with a new project, the necessary investments have to be calculated.

The total investments can be split up into four groups:

$I_B$: The investment in the process units, the on site investments or the battery limits inclusive the indirect building costs, like for example engineering and construction overhead of $I_B$.

$I_H$: The investment in side equipment, like boilers, buildings, etc., the off site investment, inclusive the indirect costs of $I_H$.

$I_L$: Investments in not touchable things, like licences, know-how, pre-operational costs, start-up costs, but not the indirect building costs.

$I_W$: The working capital, cash, terrain, supplies.

There are a couple of different methods to determine the necessary total investment sum:

- profit method (first indication)
- scale up (for the determination of the capacity)
- step methods (for route comparison)
- factor methods (rough absolute determination)
- office type (idem, but more detailed)
- detailed

These methods require more information and time in order of appearance. This also means that these methods get more accurate in order of appearance here presented and are therefore applied in this sequence as the design goes from its begin towards its ending stage.

In the next paragraphs these methods will be expanded on as much as possible based on the information found in the literature list of this section as well as specific calculations made concerning the PU-plant preliminary design.
6.2.1 Profitmethod

The profitmethod is used to make an estimation of the necessary investment. This method is based on the idea that a connection of the profits with the actual investments for a specific product can be made:

\[ r_1 = \frac{\pi}{V} \]

\[ r_v = \frac{V}{I} \]

V stands for the total profits per year made with the concerning product. The total production of Flexibles and Rigid per year are calculated as follows (with an operational time of 8640 hr/yr which equals 360 days):

Flexibles production = 714 (kg/u) * 24 * 360 = 6,168,960 kg/yr

Rigids production = 351 (kg/u) * 24 * 360 = 3,032,640 kg/yr

The going market prices are:

1 kg Flexibles = Hfl 3.--

1 kg Rigids = Hfl 3.--

These prices lead to a total profit of:

\[ V = 6,168,960 \times 3 + 3,032,640 \times 3 = \text{Hfl 27,604,800}.-- \]

The turnover ratio for the chemical industry has an average value of \( r_v = 0.75 \)

This means that the necessary investment would be in the order of \( \text{Hfl 36,806,400}.-- \)

The profit method has the following drawbacks:

- It is not practical for an instable market
- A changing market influences the investments
- Investments are assumed to be independent of capacity
- Investment is independent of the process route as well as the raw materials used
Figure 6.2 Temperature factor

Figure 6.3 Pressure factor

Table 6.1 Material factor

<table>
<thead>
<tr>
<th>$F_m$</th>
<th>CONSTRUCTION MATERIAL</th>
<th>$10^{F_m}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Cast iron, carbon steel, wood</td>
<td>1</td>
</tr>
<tr>
<td>0,1</td>
<td>Aluminium, copper, brass, stainless steel (400 series)</td>
<td>1.26</td>
</tr>
<tr>
<td>0,2</td>
<td>Monel, nickel, inconel stainless steel (300 series)</td>
<td>1.58</td>
</tr>
<tr>
<td>0.3</td>
<td>Hastelloy, etc.</td>
<td>2.0</td>
</tr>
<tr>
<td>0.4</td>
<td>Precious metals</td>
<td>2.5</td>
</tr>
</tbody>
</table>
6.2.2 Step Method

The Zevnik-Buchanan method:

This method is based on the fact that the investments are a function of two variables:

- process capacity
- process complexity

For an estimation of the investments just four basic data elements are necessary:

- process capacity
- total number of functional units (N) from the process flow diagram
- a complexity factor (Cf)
- Plant Cost index (Ci)

A functional unit is an apparatus with belongings for example a distillation column with pumps, piping and instrumentation. The basis of this method is the assumption that the functional units would be just as expensive independent of the process under the condition that a correction is made for the process conditions like temperature, pressure, etc. This correction factor is put together in the form of the complexity factor.

The calculation proceeds as follows:

1. Determine the maximum temperature to be reached and determine the temperature factor (Ft) from figure 6.2:

\[ F_t = 0.018 \left( \frac{T - 290}{100} \right) \quad \text{if } T > 290 \, \text{K} \]

\[ F_t = -0.20 \left( \frac{T - 290}{100} \right) \quad \text{if } T \leq 290 \, \text{K} \]

The maximum temperature occurs in the reactor: 200°C

\[ F_t \text{ at this temperature becomes: } F_t = 0.033 \]

2. Determine the maximum reached pressure in the process and read the pressure factor (Fp) from figure 6.3:

The maximum pressure is reached in the reactor and is 3 bar.

\[ F_p \text{ at this pressure becomes: } F_p = 0.05 \]

3. Once a choice is made concerning the construction material used, the material factor (Fm) can be read from table 6.1. The material chosen is carbon steel. This because of the fact that all requirements, for example strength and corrosion, are met using this material.

This leads to \[ F_m = 0. \]

6.4
Methode van Zevnik-Buchanan
Bepaling: Prijs per functionele unit
Basis: 1978

Figure 6.4 Investment per functional unit
4. Calculate the complexity factor \( (C_f) \):

\[
C_f = 2 \times 10^{(r_1+r_2+r_3)} = 2.42
\]

5. Read from figure 6.4 the investments per functional unit \( (I_B) \). Calculation of \( I_B \) is done with a degression factor of \( m = 0.6 \) for processes with a production > 4500 ton/yr. For a smaller production \( m = 0.5 \) is chosen.

The production equals 6,168,960 + 3,032,640 = 9,201,600 kg/yr.
This is \( 9.2 \times 10^5 \) tons/yr.
From figure 6.4 an \( I_B = $0.30 \times 10^6 \)

6. Calculate the investment:

\[
I_B + I_H = N \times I_B \times 1.33 \times (C_I / 219)
\]

\[
C_I = C.E. \text{ Plant Cost Index} = 357.6 \text{ (see table 6.2)}
\]

The number of functional units \( N \) is composed of:

- The Feed Section:
  - 2 Cutters
  - 2 Mixers
  - 1 Flash vessel
  - 1 Stripper
  - 1 Gas dryer
  - 4 Pumps

- Reaction Section:
  - 2 Agitated vessels
  - 1 Filter system
  - 1 Settler
  - 1 Distillation column

- Work-up Section:
  - 1 Rotating Disc Extractor
  - 1 Flash vessel
  - 2 Ion Exchangers

- Rest:
  - 11 Heat exchangers

Total:

\[
N = 56
\]

\[
I_B + I_H = 56 \times 0.30 \times 10^6 \times 1.33 \times (357.6/219)
\]

\[
= $36.5 \times 10^6
\]

\[
= f66.8 \times 10^6 \text{ (1 dollar = 1.83 Dutch guilders)}
\]
Table 6.2 Cost index numbers
I_n = N \times 0.1 \times C_I \times p^m \times C_I

in which:  
- \( p \) = production in kilotons
- \( m \) = degradation exponent (0.6)
- \( I_B \) = investment in \$ 10^6

\[ I_B = 56 \times 0.1 \times 2.42 \times [8.5]^{0.6} \times 357.6 \]
\[ = 17 \times 10^6 \]
\[ = \text{Hfl} 32 \times 10^9 \]

An objection to this method is that different units from a process plant could very well operate under different process conditions. Better results are therefore achieved when the calculation is performed for each unit separately.

### 6.2.3 Factor Methods

Factor methods are based on the fact that two thirds of the investments are made up of material costs from which in turn two thirds are apparatus costs. In order to use this method the total apparatus costs must be known.

These costs can be obtained in different ways:

- from offers (O)
- WEBCI [3] (W)
- methods based on the dimensions of the apparatus, corrected for pressure, type, material and price index. (A)

For the last method mentioned, a sufficient overview is given in the literature survey of Olujic [1]. The calculation method as well as the results are given in Appendix 6.1. The calculated apparatus costs are given in table 6.3 in Appendix 6.1.

### Method from Lang

A first estimation with the factor method is given by Lang. Here the total apparatus costs are multiplied with the Lang-factor. The thought behind this method is the following:

1. The costs of apparatus, supplied but not yet installed, are equalled to 1,00 (A).
2. Because of the costs of fundament, supports and installation these costs rise to 1,43: \( B = 1,43 \times A \).
3. For the necessary piping the costs \( B \), for mixed processes, has to be multiplied with 1,25. So \( C = B \times 1,25 \).
4. The costs for electrical installations and site services, are found by multiplying \( C \) with 1,5. So \( D = C \times 1,5 \).
$f_1$, process-piping factors are:

<table>
<thead>
<tr>
<th>Range</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.07 to 0.10</td>
<td>Solids processing</td>
</tr>
<tr>
<td>-0.10 to 0.30</td>
<td>Mixed solids-fluid processing</td>
</tr>
<tr>
<td>0.30 to 0.60</td>
<td>Fluid processing</td>
</tr>
</tbody>
</table>

$f_2$, instrumentation factors are:

<table>
<thead>
<tr>
<th>Range</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.02 to 0.05</td>
<td>Little automatic control</td>
</tr>
<tr>
<td>-0.05 to 0.10</td>
<td>Some automatic control</td>
</tr>
<tr>
<td>0.10 to 0.15</td>
<td>Complex automatic control</td>
</tr>
</tbody>
</table>

$f_3$, building factors are:

<table>
<thead>
<tr>
<th>Range</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05 to 0.20</td>
<td>Outdoor units</td>
</tr>
<tr>
<td>0.20 to 0.60</td>
<td>Mixed indoor and outdoor units</td>
</tr>
<tr>
<td>~0.60 to 1.00</td>
<td>Indoor units</td>
</tr>
</tbody>
</table>

$f_4$, facilities factors are:

<table>
<thead>
<tr>
<th>Range</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 0.05</td>
<td>Minor additions</td>
</tr>
<tr>
<td>0.05 to 0.25</td>
<td>Major additions</td>
</tr>
<tr>
<td>0.25 to 1.00</td>
<td>New site</td>
</tr>
</tbody>
</table>

$f_5$, outside lines factors are:

<table>
<thead>
<tr>
<th>Range</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 0.05</td>
<td>Existing plant</td>
</tr>
<tr>
<td>-0.05 to 0.15</td>
<td>Separated units</td>
</tr>
<tr>
<td>0.15 to 0.25</td>
<td>Scattered units</td>
</tr>
</tbody>
</table>

$f_6$, engineering and construction factors are:

<table>
<thead>
<tr>
<th>Range</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>~0.20 to 0.35</td>
<td>Straightforward plants</td>
</tr>
<tr>
<td>0.35 to 0.50</td>
<td>Complex plants</td>
</tr>
</tbody>
</table>

$f_7$, size factors are:

<table>
<thead>
<tr>
<th>Range</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 0.05</td>
<td>Large plants</td>
</tr>
<tr>
<td>~0.05 to 0.15</td>
<td>Small plants</td>
</tr>
<tr>
<td>0.15 to 0.35</td>
<td>Experimental plants</td>
</tr>
</tbody>
</table>

$f_8$, Contingency factors are:

<table>
<thead>
<tr>
<th>Range</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.10 to 0.20</td>
<td>Firm process</td>
</tr>
<tr>
<td>0.20 to 0.30</td>
<td>Process subject to change</td>
</tr>
<tr>
<td>0.30 to 0.50</td>
<td>Tentative process</td>
</tr>
</tbody>
</table>

Table 6.3 F - factors
5. To bring the indirect costs into account, this factor is multiplied with 1.38 \( (1.38 \times D) \).

This leads to a total of 3.7*A for mixed processes (solid/fluid).

The total necessary investment becomes: \( 3.7 \times 1,913,400 = \text{Hfl. 7,079,580} \).--

**Correction Lang factor according to the Montfoort method**

This method is based on the fact that the Lang factor becomes smaller when the average price per unit increases. This relation is given by the following equation:

\[
L = 10 \times E^{0.22}
\]

in which \( E = \) average unit costs in Hfl. 1000.

With a total number of 65 units and a total price of 1,913,400 this leads to \( E = 29.4 \)

The Lang factor therefore becomes: 4.8

This means that the total investment becomes \( 4.8 \times 1,913,400 = 9,184,320 \)-- Hfl.

**6.2.4 Offsite Facilities**

The calculation of the costs of site preparation, industrial buildings, storage facilities, utility plants, auxiliary facilities and offsite piping, is done with the help of the total unit costs and the belonging factors. These factors are taken from Guthrie [4] (see figure 6.5 in Appendix 6.0) and are common values for the a chemical plant.

The average unit costs are necessary in order to determine the belonging factors. This price is determined with the Lang factor, corrected with the Montfoort method. This factor is: 4.8

<table>
<thead>
<tr>
<th>Facility</th>
<th>Cost factor</th>
<th>Costs [Hfl]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site preparation</td>
<td>5.0 %</td>
<td>459,200</td>
</tr>
<tr>
<td>Industrial buildings</td>
<td>4.0 %</td>
<td>367,400</td>
</tr>
<tr>
<td>Storage facilities</td>
<td>8.0 %</td>
<td>734,700</td>
</tr>
<tr>
<td>Utility plants</td>
<td>4.5 %</td>
<td>413,300</td>
</tr>
<tr>
<td>Auxiliary facilities</td>
<td>1.5 %</td>
<td>137,800</td>
</tr>
<tr>
<td>Offside piping</td>
<td>2.5 %</td>
<td>248,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>-</td>
<td><strong>2,360,400</strong></td>
</tr>
</tbody>
</table>
It has to be mentioned that a company like ICI already has most of these facilities at their convenience so that this calculation is based on the fact that the plant would be build from scratch at a different site.

Finally the total investment becomes Hfl 11,545,000.-- (9,184,320 + 2,360,400)

In the further calculations this value of total investment will be used because in this stage of the design the Factor method is the most reliable and accurate one.

6.3 The Variable Costs $K_v$

The variable costs, or the production-dependent costs, are in the used simple model the total cost of raw materials and used external resources. In the last one are the energy cost the most important. The total of the variable costs can be calculated with:

$$K_v = \sum q_i v_i$$

where $q_i =$ amount of used resource $i$.

$v_i =$ price of used resource $i$.

In this equation is assumed that the $v_i$ is a constant. This is a simplification of reality. A more detailed description is given in Montfoort [2]. The total variable cost can be divided in three parts. These are the total costs of raw materials ($K_{p,raw}$), the total energy costs ($K_{p,energy}$) and the total costs of other external resource costs like costs cooling water.

$$K_v = \sum K_{p,raw} + \sum K_{p,energy} + \sum K_{p,others}$$

6.3.1 Calculation of $K_{p,raw}$

From the mass balance given in chapter 4, the converted amount of raw materials are given in table 6.4. In table 6.4 are also given the corresponding prices of the used raw materials. These prices are taken from Shell [5], ICI [6], Merck [7].

<table>
<thead>
<tr>
<th>Material</th>
<th>Amount [kg/h]</th>
<th>Price [Hfl/kg]</th>
<th>$K_{p,1}$ [Hfl/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>PU</td>
<td>1000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>MEG</td>
<td>275</td>
<td>1.--</td>
<td>275.--</td>
</tr>
<tr>
<td>KAC</td>
<td>20</td>
<td>10.--</td>
<td>200.--</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\Sigma K_{p,raw} =$</td>
<td>475.--</td>
</tr>
</tbody>
</table>

Table 6.4
6.3.2 Calculation of $K_p_{\text{energy}}$

For the calculation of the total energy cost the energy balance given in chapter 4 is used. The required energy is used for heating or for shaft work. For heating there are two different heating sources used steam and hot oil. From the given P.F.D. it follows that in the heat exchangers:

- H4 and H7: hot oil is the heat source.
- H13: saturated steam is the heat source.

In chapter 4 is given that the steam rate in heat exchanger H13 is 1.37 kg/s = 40.08 kg/h. In 6.II the needed amount of natural gas to heat up the oil which is used in heat exchangers H4 and H7. This amount of natural gas is:

$$0.40 \text{ m}^3/\text{s} \text{ or } 1440 \text{ m}^3/\text{h}$$

Electrical power is used for pumping of the fluid. In chapter 4 is calculated that for pumping is 12 KW is needed. Also some apparatus used electrical power. For the three section are these apparatus given in table 6.5. From Webci [3] the prices of the different energy carriers are taken.

1 Electrical power $V_{el} = 0.15 \text{ Hfl/kWh}$.
2 natural gas $V_{gas} = 0.21 \text{ Hfl/m}^3$.
3 saturated steam $V_{steam} = 0.03 \text{ Hfl/kg}$.

<table>
<thead>
<tr>
<th>apparatus</th>
<th>Duty(KW)</th>
<th>$\Sigma K_{p1}$ (Hfl/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>elec.</td>
<td>gas</td>
<td>steam</td>
</tr>
<tr>
<td>H13</td>
<td></td>
<td>33</td>
</tr>
<tr>
<td>H4, H7</td>
<td>4974</td>
<td></td>
</tr>
<tr>
<td>pumps</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>cutters</td>
<td>191</td>
<td></td>
</tr>
<tr>
<td>H.S.M.</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>3 mixers</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>R.D.C</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>screw</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\Sigma K_{p_{\text{energy}}}$</td>
</tr>
</tbody>
</table>

Table 6.5
6.3.2 Calculation of \( K_p \) others

The total costs of external resources other than energy and raw materials are for this process only the costs of cooling water in the used heat exchanger and condensers. In 6.1111 is given a detailed calculation of the used amount of cooling water.

This amount is \( q_{cw} = 11.1 \text{ m}^3/\text{h} \).

According to Webci [3] is the price of cooling water 0.06 Hfl/m\(^3\) when river water is used or water from recirculation in a cooling tower. The total costs of cooling water is: \( 11.1 \times 0.06 = 0.66 \text{ Hfl/h} \) Compared to the energy and raw material costs the cooling water costs can be neglected.

The total of variable costs is \( K_p = K_{p \text{raw}} + K_{p \text{energy}} = 475 + 340 = 815 \text{ Hfl/h} \)

The total variable cost per kg PU is \( = 815/1000 = 0.82 \text{ Hfl/kg PU} \)

6.4 Costs of labour \( L \)

The labour costs is calculated with:

\[
L = q_{\text{labour}} \times v_{\text{labour}}
\]

where \( q_{\text{labour}} \) is the amount needed of man-hour.

\( v_{\text{labour}} \) is the price of labour per hour.

The amount of needed man-hour is calculated with the Wessel correlation from Montfoort [2].

\[
\frac{M_h}{T_p} = k \times \frac{sts}{(\frac{T_p}{\text{day}})^{0.76}}
\]

where \( M_h = \text{man-hours} \).

\( T_p = \text{ton product} \).

\( sts = \text{amount of steps in the process} \).

\( k = \text{Wessel coefficient} \).

The amount of man-hour is dependent of

1. The kind of process (batch or continue)
2. Production capacity
3. Working efficiency

6.10
According to Montfoort [2] was \( k = 3 \) in 1986 because it is a combination of batch and continue process. The \( k \)-value reduces annually with about 6%. For 1992 the \( k \)-value becomes 2. The 9 steps in the process are:

1. Cutting of crude PU.
3. Water removal and MEG recovery.
4. Reaction.
5. Settler.
6. Distillation.
7. Extraction.
8. Flash.
9. Ion exchanger.

When \( \text{sts} = 9 \)
\[ k = 2 \]
\[ t_p = 24 \times (0.714 + 0.351) = 25.56 \text{ ton products per day} \]

Then the needed about Man-hour is: \( M_h = 1.5 \) per produkt.

Annually the flexible and rigid production is 9,201.6 ton. This amount multiplied by the man-hour gives the needed amount of man-hour in one year. This is 13,802 hour. When this process operates on continue bases than is the man-hour on one employment site 8760 hour. This means that for this process the needed employment sites are:

\[ \frac{13802}{8760} = 1.6 = 2 \]

In 1992 is the cost of one employment site in one about Hfl 400,000 and in one year will be processed \( Q = 8,640,000 \) kg PU. For two sites the total labour costs per kg PU become:

\[ L = 0.10 \text{ Hfl/kg PU} \]

The operational costs: \( K_{\text{operational}} = (K_p + L) \times Q = \text{Hfl} \ 7.95 \times 10^6 \)
<table>
<thead>
<tr>
<th>Rentevoet</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>8</th>
<th>10</th>
<th>15</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>103</td>
<td>53</td>
<td>35</td>
<td>27</td>
<td>22</td>
<td>14</td>
<td>11.7</td>
<td>8.4</td>
<td>6.7</td>
</tr>
<tr>
<td>4</td>
<td>104</td>
<td>53</td>
<td>36</td>
<td>28</td>
<td>22</td>
<td>15</td>
<td>12.3</td>
<td>9.0</td>
<td>7.4</td>
</tr>
<tr>
<td>5</td>
<td>105</td>
<td>54</td>
<td>37</td>
<td>28</td>
<td>23</td>
<td>16</td>
<td>13.0</td>
<td>9.6</td>
<td>8.0</td>
</tr>
<tr>
<td>6</td>
<td>106</td>
<td>55</td>
<td>37</td>
<td>29</td>
<td>24</td>
<td>17</td>
<td>13.6</td>
<td>10.3</td>
<td>8.7</td>
</tr>
<tr>
<td>8</td>
<td>108</td>
<td>56</td>
<td>39</td>
<td>30</td>
<td>25</td>
<td>18</td>
<td>14.9</td>
<td>11.7</td>
<td>10.2</td>
</tr>
<tr>
<td>10</td>
<td>110</td>
<td>58</td>
<td>40</td>
<td>32</td>
<td>26</td>
<td>19</td>
<td>16.3</td>
<td>13.1</td>
<td>11.8</td>
</tr>
<tr>
<td>12</td>
<td>112</td>
<td>59</td>
<td>42</td>
<td>33</td>
<td>28</td>
<td>20</td>
<td>17.7</td>
<td>14.7</td>
<td>13.4</td>
</tr>
<tr>
<td>15</td>
<td>115</td>
<td>62</td>
<td>44</td>
<td>35</td>
<td>30</td>
<td>22</td>
<td>19.9</td>
<td>17.1</td>
<td>16.0</td>
</tr>
<tr>
<td>20</td>
<td>120</td>
<td>65</td>
<td>47</td>
<td>39</td>
<td>33</td>
<td>26</td>
<td>23.9</td>
<td>21.4</td>
<td>20.5</td>
</tr>
</tbody>
</table>

Table 6.5A Values of capital charge
6.5 Total Costs ($K_T$)

The total costs can now be calculated by adding all the known cost and coefficients in the following equation:

$$K_T = a \cdot K_p + f \cdot I + d \cdot L$$

As mentioned in figure 6.1a

$$K_T = 1.13 \cdot 0.82 + 2.6 \cdot 0.10 + 0.13 \cdot \frac{11,545,000}{8,640,000}$$

As mentioned in 6.3 the coefficient $f$ has not included the interest and the depreciation on the investment. Assuming that the interest rate is 8% and the period for the depreciation is 10 years. According to table 6.5A the capital charge = 14.9%. Correction of $f$ for this capital charge becomes the new value of the total costs per kg PU:

$$K_T = 1.36 + 0.149 \cdot \frac{11,545,000}{8,640,000} = 1.56 \frac{Hf}{kg PU}$$

When this calculated cost is compared with another PU-waste treating process, like burning the PU foam by a waste treatment company, appeared that this process is much more expensive. According to AVR[8] the burning of PU foam costs 0.45 Hf/kg PU.

6.6 Economic Criteria

In this chapter the emphasis is put on measuring on economic basis, with the purpose of helping to make choice concerning the actual realization of the project.

The following criteria are used:

- Pay Out time
- Return On Investment (ROI)
- Internal rate of return

6.12
6.6.1 Pay Out time

The Pay Out time is defined as the minimal number of years needed to earn back the original investment. The original investment is formed only by the deductible fixed capital investment; the work capital is not taken into consideration.

The calculation takes into account a surplus $E_0$. This value $E_0$ is found by reducing the profit with the variable as well as the semi-variable costs.

The Pay Out time is then calculated by dividing the investment with the exploitation surplus.

The total investment is Hfl 11,545,000--

The exploitation surplus is formed by:

$$E_0 = \text{profit} - \text{operational costs}$$

profit = Hfl 27,6 \times 10^6
operational costs = Hfl 7.95 \times 10^6

This implicates a Pay Out time of: 0.7 year

The disadvantages of the Pay Out time method are:
- time factor of currency is not taken into account
- building time
- interest and operational load

6.6.2 Return on Investment

With this method the annual profits are divided by the total investments. Multiplying with 100 gives the Return on Investment (ROI):

$$\text{ROI} = \left\{ \frac{W}{(I_r + I_w)} \right\} \times 100$$

in which:
- $I_r$ = investment in apparatus
- $I_w$ = investment in work capital
- $W$ = profit

The calculation is based on a full operation load meaning that the operational load reduction, for as far as applicable, is not taken into account. To gain insight into different circumstances, the ROI is also calculated at different production rates in volume or profits. Here a calculation is made for 10% of the full load.

The calculation of the ROI is given in Table 6.6 and 6.7.

Disadvantages of this method are:
- The change of currency with time is not taken into account
Fluctuations of production rates and costs in time are not taken into account.

<table>
<thead>
<tr>
<th><strong>Full load: (amounts given in Hfl.)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed investment</td>
</tr>
<tr>
<td>Workcapital (5 %)</td>
</tr>
<tr>
<td>Total investment (f)</td>
</tr>
<tr>
<td>Profits per year</td>
</tr>
<tr>
<td>Operational costs</td>
</tr>
<tr>
<td>Difference (a)</td>
</tr>
<tr>
<td>Depreciation (b), 8.25 % per yr</td>
</tr>
<tr>
<td>(of fix. inv.)</td>
</tr>
<tr>
<td>Taxable income (c), (a-b)</td>
</tr>
<tr>
<td>Taxes (d), (50 % van c)</td>
</tr>
<tr>
<td>Net income (e), (c-d)</td>
</tr>
<tr>
<td>Return On Investment</td>
</tr>
</tbody>
</table>

Table 6.6 Calculation of the ROI.

<table>
<thead>
<tr>
<th><strong>Profits 10 % lower than expected: (amounts given in Hfl.)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed investment</td>
</tr>
<tr>
<td>Workcapital (5 %)</td>
</tr>
<tr>
<td>Total investment (f)</td>
</tr>
<tr>
<td>Profits per year</td>
</tr>
<tr>
<td>(0.9 * full load profits)</td>
</tr>
<tr>
<td>Operational costs</td>
</tr>
<tr>
<td>Difference (a)</td>
</tr>
<tr>
<td>Depreciation (b), 8.25 % per yr</td>
</tr>
<tr>
<td>(of fix. inv.)</td>
</tr>
<tr>
<td>Taxable income (c), (a-b)</td>
</tr>
<tr>
<td>Taxes (d), (50 % van c)</td>
</tr>
<tr>
<td>Net income (e), (c-d)</td>
</tr>
<tr>
<td>Return On Investment</td>
</tr>
</tbody>
</table>

Table 6.7 Calculation of the ROI.
6.6.3 Internal rate of return

With this method the cash flows, including the investment, over the actual duration period of the project, are calculated into the present value with such a return percentage r, that the sum of these negotiated cash-flow’s (DCF’s) over the duration period of the project equals zero. The value of r found with this method then functions as the economic criterion.

The work capital as well as the rest value are put at 5% of the investment.

- investment \( \text{Hfl} 11.5 \times 10^6 \)
- work capital \( \text{Hfl} 0.6 \times 10^6 \)
- rest value \( \text{Hfl} 0.6 \times 10^6 \)
- project period 10 yr

For the convenience the cash flows are kept constant over the project duration period. The cash flows are given in table 6.8.

<table>
<thead>
<tr>
<th>Year</th>
<th>Average cash flow</th>
<th>Average cash flow in Hfl</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Investment</td>
<td>-12,122,250 (a)</td>
</tr>
<tr>
<td>2</td>
<td>Net income</td>
<td>9,351,669 (b)</td>
</tr>
<tr>
<td>3</td>
<td>Net income</td>
<td>9,351,669 (c)</td>
</tr>
<tr>
<td>10</td>
<td>Net income + rest value</td>
<td>9,651,669 (m)</td>
</tr>
</tbody>
</table>

Table 6.8

The internal rate of return (IRR) than follows from the following formula:

\[
a + b/(1+i) + c/(1+i)^2 + \ldots + m/(1+i)^n = 0
\]

\[
n = \text{project duration period}
\]

\[
-12,122,250 + 9,351,669/(1+i) + 9,351,669/(1+i)^2 + \ldots + 9,951,669/(1+i)^{10}=0
\]

Analytical solving of the equation yields \( \text{IRR} = i = 0.8\% \)
6.7 **Conclusion**

From the given Flowsheet the total investment cost is calculated using the Factor Method. One should keep in mind that the treatment of the rigids coming out the distillation column is not included in this preliminary plant design. The required total Investment is:

\[ I = 11,545,000 \text{ Hfl} \]

From the mass balance, the energy balance given in chapter 4 of the Report and the Labour costs (2 labour sites calculated with the Wessel correlation) the annual operational are

\[ K_{\text{operational}} = 7,949,000 \times 1.53 \text{ Hfl/kg PU} \]

The total costs of PU recycling with this process is calculated using the simplified model. These total costs are based on the site costs, not taking into account the costs of getting the materials to the site and the costs for distributing the final products of the plant. When with this plant annually 8,640,000 Kg PU is processed the total costs of the PU recycling becomes:

\[ K_r = 1.56 \text{ Hfl/kg PU} \]

This is more expensive than burning the PU by a waste treatment company like AVR. But the products (Flexibles and Rigids) recovered in this PU-recycling plant are valuable (market price for both is 3 Hfl/kg). According to the made rough calculations on the turnover and profit this process is feasible and even profitable.
Poly Urethane Recycling

Cost Engineering

Literature


2. A.G. Montfoort, *Dictaat Chemische Fabriek deel 3, st44 TUD, Delft 1989*


5. Shell, personal conversation with Shell Hofplein 19 about the price of MEG.

6. ICI, personal conversation with ICI Rozenburg about the price of PU.

7. Merck, personal conversation with Merck Amsterdam about the price of KAC.

8. AVR, personal conversation with Afval Verwerking Rijnmond about the price of burning the PU foam.
7 SUMMARY OF THE ENVIRONMENTAL POLLUTION FROM THE PU-RECYCLING FACTORY

The summary is divided in effects on bottom, surface water, air and other discharges. Also there is a difference between normal industrial circumstances and the occurrence of disasters.

7.1 Normal Industrial Circumstances

7.1.1 Bottom

There has to be no other use of the bottom than support of the buildings. Also there has to be no discharge of wastes to the bottom, so using tanks for catching liquids and using a floor which does not let through liquids. The environment of the plant is an industrial one.

7.1.2. Surface Water

The PU-recycling factory is able to take cooling water from surface water. There has to be no discharge of poisonous wastes to the surface water. The waste water stream meets to the requirements for waste streams in the environment. Liquid wastes have to be avoided, if the release of materials into water sources or supplies which are damaging to life because of their toxicity, and/or their reduction of the normal oxygen level of the water, or because they are aesthetically unpalatable.

The fouled water from the ion exchanger column 0.055 m³/day contains HCl. This HCl can be neutralized with a base by a conventional treatment, before the fouled water is drained off.

HCl + DADPM from the ion exchanger column 0.0165 m³/day [1] cannot drained off directly to the surface water, because DADPM and HCl are dangerous materials for health and environment (DADPM causes cancer). DADPM has to be recovered and used in other processes.

Also the poisonous MEG cannot be discharged to the environment. MEG from distillation column and flash separator is sent to the crude MEG-storage and is recycled in the process.
7.1.3 Air

The environment is not very loaded by discharge of waste gases. The waste gas streams CO₂ and N₂ meet the requirements for waste streams in the environment.

There is no requirement for discharging CO₂ to the air, only in closed rooms if the concentration is higher than 9000 mg/m³ (is MAC-value = maximum acceptable concentration) [2] it will lead to asphyxiation.

CO₂, a colourless gas which forms 0.3 percent of normal air and is an essential raw material for photosynthetic activity by green plant. Carbon dioxide combines chemically with water to produce carbonic acid (H₂CO₃), which influences the hydrogen ion concentration (pH) of water. Gas waste CO₂ emission is the problem of environment. The concentration of CO₂ in the atmosphere increases 2 ppm per year. This leads to an increase of the temperature on the earth. The temperature increase gives change of the climate, which gives important effects for the ecosystem. This is called Green House Effect.

Carbon dioxide is also responsible in part for the atmospheric corrosion of magnesium, and perhaps of other structural metals. Therefore the limit value of the CO₂ emission must be reduced. Gas CO₂ from the reactor section streams 326.4 kg/day, this gas will pollute the atmosphere.

The water and nitrogen in gas phases are transported directly from the packed bed dryer to the atmosphere. These gasses are not dangerous for the environment.

7.1.4. Other Discharges

The other discharges on the environment of employees and neighbours are at the working plant: liberating of the chemicals used in the process (as a consequence of a leak in the system) for which MAC-values are used, the noise and the so-called pollution of the horizon.

The MAC-values are calculated from experiments for an eight-hour working-day and male employees who are in a good health according to Meerman[3]. If I.C.I. want to build the PU-recycling factory somewhere else, for example in the Third World because of the lower wage-rate there, they have to use lower MAC-values.

The noise level of the plant is comparable with the noise level of industry in the direct environment. Noise limits for all industrial situations are being set and implemented. There is considerable controversy over the interpretation of some of the present standards. Ear damage, depends on the length of exposure at different intensities and frequencies, but more annoyance can occur under all sorts of conditions.

Attention should be given to the allowable and the maximum noise limits at the plant boundary, particularly at night. Acceptable criteria on the plant vary according to how often the unit is visited by personnel and closeness of office, etc.
For continuous exposure, a reasonably steady sound should not exceed 90 dB for an 8-hour working-day. The reasonably steady sound has to be lower if the working-day is longer. Equipment suppliers should meet design criteria for sound levels. Noise standard should be specified, particularly for relief, blowdown, blow-off and control. More information is steadily becoming available to help forecast noise levels on new plant.

The environment is an industrial one and the pollution of the horizon of the plant is comparable with that of other industries.
7.2 Occurrence of Disasters

At disasters bottom, air and surface water run a risk for pollution. Then the danger for the environment is being liberated of the poisonous MEG, DADPM and HCl. This has to be prevented.

When the condensor at the second reactor falls out, it is possible that MEG together with CO₂ is liberated [1]. Prevention: a second condensor after the first condensor (H 5) to prevent that MEG will pollute the air.

When there is a fire: after fire fighting the used fire water has to be purified before drain off.

Steam and hot oil are used as heat sources, so there is a chance that the condensate will get polluted. So continuous control of the condensate is necessary in chemical industry (for example by measuring of conductivity) to anticipate in the consequences of a leak in a heat-exchanger according to Montfoort[4].
7.3 Conclusion

The PU-recycling factory is not very more dangerous than moderate chemical industry. The environmental pollution can be reduced by a good treatment (and recycling if possible) of wastes from the overall plant, then the charge of the environment is not more heavy than at a moderate chemical plant.
Literature


APPENDIX 2.I.D PIPING AND INSTRUMENTATION DIAGRAM
(preliminary)
part 4
## APPENDIX 3.1

### NAAM VAN DE STOF

<table>
<thead>
<tr>
<th>dianmidofenylmethaan</th>
<th>CAS-nummer</th>
<th>EINECS-nr</th>
<th>VN-nr</th>
</tr>
</thead>
<tbody>
<tr>
<td>4,4'-dianmidofenylmethaan</td>
<td>101-77-9</td>
<td>2029744</td>
<td></td>
</tr>
<tr>
<td>4,4'-methyleendianiline</td>
<td>60 2651</td>
<td></td>
<td>NFPA</td>
</tr>
</tbody>
</table>

### SAMENVATTING

De stof is vergiftig bij inademing, opname door de mond en aanraking met de huid. De stof is brandbaar.

### MAC-waarde (8 uur)

0,1 ppm - 0,8 mg/m³ (Huid)

### VOORZORGSMAAATREGELEN

**HANDLING:** blootstelling vermijden - voor gebruik speciale aanwijzingen raadplegen

**BESCHERMINGSMIDDELLEN:** geschikte handschoenen, beschermende kleding, gelaatsscherm, adembescherming

**OPRUIMING:** lekvloeistof opvangen in afsluitbare vaten, morsvloeistof opnemen in inert absorptiemiddel en in vaten verzamelen; adembescherming gebruiken

**OPSLAG:** op een goed geventileerde plaats bewaren

### EERSTE HULP

**HUID:** ONMIDDELLIJK verontreinigde kleding uittrekken, huid wassen met water en zeep, en naar arts verwijzen

**OGEN:** eerst spoelen met veel water gedurende minimaal 10 minuten, dan naar arts vervoeren

**INADEMEN:** frisse lucht, rust, en arts waarschuwen

**INSLIKKEN:** mond laten spoelen, 1/2 liter water laten drinken en ONMIDDELLIJK naar arts vervoeren

### TOXICITEIT

**HUID:** VERGIFTIG: omdat de stof wordt opgenomen door de huid, zie bij 'INADEMEN'

**OGEN:** roodheid, pijn, slecht zien

**INADEMEN:** VERGIFTIG: hoofdpijn, duizeligheid, blauwe huid, zwaktegevoel

**INSLIKKEN:** VERGIFTIG: hoofdpijn, duizeligheid, blauwe huid, zwaktegevoel, cyanosis

**LD50 (oraal,rat):** 347 mg/kg

**CHEMISCHE VOORZORGEN:** de stof is kankerverwekkend bij ratten en muizen bij langdurige, herhaaldelijke blootstelling kans op leverbeschadigingen

### FYSISCHE EIGENSCHAPPEN

| formule | voorkomen | sneltuip (°C) | kookpunt (°C) | dampspanning bij 20 °C (mbar) | dichtheid (water = 1) | dampdichtheid (lucht = 1) | oplosbaarheid in water (g/l @ 20°C) | relatieve moleculair massa | irreversibele fysieke eigenschappen | koolstof | deviante fysieke eigenschappen |
|---------|-----------|--------------|--------------|--------------------------------|----------------------|------------------------|----------------------------------|-----------------------------|----------------------------------|---------|-----------------------------|------------------|
| H2N(CH2CH2NH2) | geelbruine vaste stof | 92 | 398 | 0,06 | 1,1 | 6,8 | slecht | 106,3 | | | | |

### BRAND EN EXPLOSIE

<table>
<thead>
<tr>
<th>vlampunt (°C)</th>
<th>zelfontbrandingstemperatuur (°C)</th>
<th>explosiegrenzen (volume% in lucht)</th>
</tr>
</thead>
<tbody>
<tr>
<td>199</td>
<td></td>
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</tbody>
</table>

### GEVAAR:

brandbaar

### PREVENTIE:

geen open vuur, geen vonken

### BLUSSTOFFEN:

druckleerder water, poeder, alcoholbestendig schuim, koolzuur

### AANWIJZINGEN BIJ BRAND:

perslucht gebruiken

### REFERENTIES

ICI Polyurethanes, Hazard Data Sheet no 32, maart 1987

Hommel, Handbuch der gefährlichen Güter, blad 854, 1985

ICI HOLLAND BV ROZENBURG FABRIEKEN 12 13 SEPTEMBER 1990 DIAHINOIDIFENYLMETHAAN
SAMENVATTING
de stof is schadelijk bij opname door de mond
de stof is brandbaar

MAC-waarde (8 uur) 50 ppm - 125 mg/m³ Ceiling

VOORZORGSMAATREGELEN

HANDELING:

BESCHERMINGSMIDDELEN: handschoenen, veiligheidsbril, zonodig adembescherming

OPRUIMING: levendlood opvangen in afsluitbare vaten, restant weghalen met veel water

OPSLAG: gescheiden van oxidatiemiddelen droog

EERSTE HULP

HUID: verontreinigde kleding uittrekken, huid spoelen met veel water, zonodig naar arts verwijzen

OGEN: eerst spoelen met veel water gedurende minimaal 10 minuten, dan zonodig naar arts vervoeren

INADEMEN: frisse lucht, rust, en zonodig arts waarschuwen

INSLIKKEN: mond laten spoelen, 1/2 liter water laten drinken, en arts waarschuwen

TOXICITEIT

HUID: de vloeistof ontvet de huid: roodheid

OGEN: roodheid

INADEMEN: keelpijn, suheid, duizeligheid

INSLIKKEN: SCHADELIJK: buikpijn, misselijkheid, braken, suheid, duizeligheid, lever- en nieraandoeningen liet kans op dodelijke afloop

L050 (oraal, rat): 6100 - Vlkg: lethe Ie dosis voor de mens: ca 1500 mg/kg

CHRONISCH: bij experimenten met proefdieren, waarbij langdurig een hoge dosering is toegediend, zijn geboordeafwijkingen opgetreden

FYSISCHE EIGENSCHAPPEN

formule: HOCH2CH2OH
voorkomen: kleurloze viskeuze vloeistof
smeltpunt (°C): -13
kookpunt (°C): 198
dampspanning bij 20 °C (mbar): 0,06
dichtheid (water -1): 1,11
dampdichtheid (lucht-1): 2,1
oplosbaarheid in water(g/l @ 20°C): volledig
relatieve molecuulmassa: 62,1

BRAND EN EXPLOSIE

vlampt (°C): 116
zelfontbrandingstemperatuur (°C): 410
explosiegrenzen (volume% in lucht): 1,8 - 12,8

GEWAAR: brandbaar

PREVENTIE: geen open vuur

BLUSSTOFFEN: poeder, alcoholbestendig schuim, halonen, koolzuur, sproeistraal water

REFERENTIES

ICI Chemicals and Polymers, Hazard Data Sheet ethylene glycol, juni 1989
ICI Chemicals and Polymers, DIN- Safety Data Sheet monoethylene glycol, augustus 1989
NIA/VHC/Chemicals, Chemiekaart C-0065, 5e editie, 1989

ICI HOLLAND BV ROZENBURG FABRIEKEN 10 13 80 JULI 1990 ETHYLEENGLYCOL
### SAMENVATTING

De stof heeft geen bijzondere gevaarseigenschappen. De stof is brandbaar.

### MAC-waarde (8 uur)

Niet vastgesteld.

### VOORZORGSMAATREGELEN

**HANDING:**
- Handschoenen, stofbril, zonodig adembescherming (stofmasker P1)

**OPRUIMING:**
- Gemorste stof opscheppen, restant wegspoelen met veel water
- Geschieden van zuren droog

**OPSLAG:**
- Gescheiden van zuren
- Droog

### EERSTE HULP

**HUID:**
- Verontreinigde kleding uittrekken, huid spoelen met veel water

**OGEN:**
- Eerst spoelen met veel water gedurende minimaal 10 minuten, dan naar arts vervoeren
- Keelpijn, hoesten

**INSLIKKEN:**
- Mond laten spoelen, 1/2 liter water laten drinken, arts waarschuwen
- Buikpijn, braken

**LD50 (orale rat):**
- 3250 mg/kg

**CHRONISCH:**
- Er zijn geen aanwijzingen voor lange-termijn effecten

### FYSISCHE EIGENSCHAPPEN

- **Formule:** CH₃COOK
- **Voorkomen:** Witte hygroscopische kristallen
- **Smeltpunt (°C):** 292
- **Kookpunt (°C):** Ontleedt
- **Dampspanning bij 20 °C (mbar):** 1,8
- **Dampdichtheid (lucht-1):**
- **Oplosbaarheid in water (g/l @ 20°C):** 2530
- **Relatieve molecule massa:** 98,2

### BRAND EN EXPLOSIE

**Vlampunt (°C):**

**Zelfontbrandingstemperatuur (°C):**

**Explosiegrenzen (volume% in lucht):**

**GEVAAR:**
- Brandbaar; fijn verdeeld stof, met lucht explosief

**PREVENTIE:**
- Stofafzetting voorkomen, geen open vuur

**BLUSSTOFFEN:**
- Sproeistraal water, poeder

### REFERENTIES

ICI Chemicals and Polymers, Hazard Data Sheet potassium acetate, september 1982
NIA/VNCI/Samson, Chemiekaart C-0693, 5e editie, 1989
ICI HOLLAND BV ROZENBURG FABRIEKEN 81
MAART 1991
I

1. CHOICE, SITUATION AND LAYOUT OF SITE

When considering the suitability of a site for establishing a chemical plant it must be investigated whether all the requisite safety conditions can be met on that particular site. If not then this may imply the necessity of looking for a more suitable site.

1.1 CHOICE AND SITUATION OF SITE

1.1.1 Dimensions of site

1.1.1.1 Size

The site should be large enough for a safe layout of the individual plants. There should be sufficient room for parking facilities, platforms for loading and unloading, service buildings, stores, storage tanks, purification installations and possible future extensions.

1.1.2 Nature of site: geophysical factors

1.1.2.1 Waterlevel

The site should be safeguarded against floods, high water table, strongly fluctuating water table and similar.

1.1.2.2 Nature of the soil

The soil should be sufficiently firm to prevent sagging and sliding. The following aspects are of importance in this respect.

Settling

Settling of the soil can be expected in areas where water is withdrawn, with backfilled soil and near former refuse-dumps, brooks and dikes.

Ground disturbances

Account should be taken of existing or expected geological disturbances and mine-disturbances.

Acidity

Investigation of the soil acidity is necessary to anticipate possible chemical attack of foundations, cables, pipes, tanks etc.

1.1.2.3 Relief and slope

If a sloping site is selected it should be checked which precautions are necessary to prevent liquids, gases or fumes from reaching lower levels where they may constitute a hazard.

1.1.3 Climatological conditions

For a full evaluation of the safety measures to be taken at the site the climatological conditions are to be considered.

1.1.3.1 In connection with the dispersion of volatile and inflammable and/or harmful substances over the site and the windward positioning of ignition sources a study of the wind rose is necessary.

1.1.3.2 Calm conditions enhance the probability of increased concentrations of inflammable and/or poisonous fumes and gases at the site.

Owing to the presence of condensation nuclei (e.g. from cooling towers and very finely divided liquid or dust particles) the probability of fog formation may be enhanced.

1.1.3.3 Precipitation and temperature

The influence of climatological factors (such as precipitation and temperature) on the safety of a process are discussed in other chapters (civil-technical provisions, equipment, and general fire-fighting provisions).

1.1.4 Accessibility of the site

1.1.4.1 Road traffic

The supply and delivery routes of raw materials and final products should be safe with respect to the nature of the substances. Account should be taken of the ban on transporting certain dangerous substances through tunnels (see also 1.2.4). Further, facilities should be provided for the safe integration of cars, lorries, cyclists, pedestrians etc. from the site into the flow of traffic.

1.1.4.2 Railway

If rail transport is required it should be checked whether a safe connection with the existing railway system is possible.

1.1.4.3 Water

The possibilities for safe mooring, loading, unloading and manoeuvring of vessels have to be investigated.

1.1.4.4 External assistance

With a view to external assistance (fire brigade, medical service) the access roads should be free from obstacles such as level railway crossings, movable bridges, shunting-yards and the like.
1.1.5 General provisions

1.1.5.1 Fire fighting
An adequate supply of water should be available.

1.1.5.2 Drainage
Draining of rain water, fire water and process water should not only be technically possible but should also be considered in the light of environmental control.

1.1.5.3 Waste products
If waste products are produced then the methods of removal, temporary storage, processing and/or destruction are to be studied.

1.1.5.4 Energy
If energy is provided the reliability of generation and its supply should be investigated.

1.1.5.5 Situation of site with regard to effects by and on the environment.

1.1.6.1 Environmental control
Factors concerning environmental control and nuisance can be of decisive significance in the selection of the site and for its situation (see preface). Some industries are very sensitive to certain types of air and/or water pollution. The presence of hydrocarbons in the intake of air separation equipment and air compressors etc. are examples of this.

1.1.6.2 Adjacency
It should be investigated what is present or in preparation at the adjacent sites, and what adverse interaction could ensue as a consequence. Not only the normal process conditions should be considered in this case, but in particular abnormal events, e.g. process interruptions. Pipeline tracks may constitute a source of danger or be endangered by traffic or incidents in nearly industries.

1.1.6.3 Ignition sources
Internal and external ignition sources may mutually and adversely affect the safety of the various industries involved. External ignition sources may include adjacent public roads, railways, overhead high tension cables, and open fire on neighbouring sites.

1.1.6.4 Vibration
It should be checked whether nearby industries cause vibrations that are unacceptable for sensitive instruments or equipment. Further it should be investigated how far personnel are exposed or are going to be exposed to sound nuisance.

1.1.6.5 Stacks and other high structures
If the site is situated in the neighbourhood of an airfield it is to be investigated whether stacks and other high structures will constitute a hazard to aviation.

1.2 LAYOUT OF SITE

1.2.1 Administration buildings, service buildings and parking facilities.

1.2.1.1 Concentrations of people
Offices, laboratories, canteens and workshops where concentrations of people occur should be adequately segregated from hazardous locations so that under normal operational conditions as well as during interruptions they will be protected from hazards.

1.2.1.2 Internal traffic
In order to limit traffic, buildings that are not directly involved in the production process (including general stores, water preparation plants and similar) should be located at the periphery of the site.

1.2.1.3 Parking lots
Parking lots for passenger cars, lorries, road tankers and buses should be planned on the outside of the site or entirely outside the fenced area. A smooth dissolution of traffic during rush-hours, and safe entries and exits of parking lots and factory grounds merit special attention.

1.2.2 Private roads and internal railroads

1.2.2.1 Limitation road traffic
The rail and road plan should be such that road traffic in the operating area is minimized.

1.2.2.2 Accessibility
The roads should ensure adequate, multiple access to factory buildings, installations and stores (for service and fire fighting). To this end in large production units the plant sections can be separated by roads. The road plan at and near the loading and unloading bays should provide the possibility for the vehicles to manoeuvre, wait and turn in a
safe way.

1.2.2.3 Railway lines
Railway lines should be planned at ample distance from hazardous process units. In large production complexes a railway line traversing a production zone should be avoided wherever possible. The place to load, unload and shunt railway wagons should be chosen such as to exclude prolonged and/or frequent blocking of road traffic.

1.2.3 Factories, process units, and auxiliary installations.
1.2.3.1 Situation
Vulnerable and potentially hazardous units should be situated such that in the event of serious disruptions and incidents the consequences are localized to those particular units.

1.2.3.2 In order to attain adequate multiple accessibility large installations should be built in an elongated manner (which is often to the detriment of effective factory management), or they should be divided into logical units separated by compound roads.

1.2.3.3 What is said in 1.2.3.2 arises from the requirement that in order to fight a fire effectively it is essential that fire water, foam and the like can be applied from several directions. Further the water should be drained in such a way that any inflammable liquids floating on the water are prevented from spreading over other areas. The site roads also serve as fire lanes to check the fire.

1.2.3.4 When positioning the equipment and the associated pipelines attention should also be given to necessary future maintenance, so that this can take place simply (and hence also safely). Included herein should be routine internal and external inspections, the removal and reinstallion of relief valves and similar.

1.2.3.5 The advantages of installing equipment within a building (protection of personnel and equipment against wind, rain and frost) are to be balanced against the disadvantages (impediment in fire fighting, poorer dispersion of escaped substances in most cases and hence higher concentrations with inherent toxicity and explosion hazards).

1.2.3.6 Pipe tracts
The installation should preferably be limited by a pipebridge at one side only. High vehicles, cranes etc. may damage pipes if these are mounted above roads; these overhead crossings should be limited. If feasible use is to be made instead of trough or channels. The equipment should be placed in such a way that there is the smallest possible chance of damage.

1.2.3.7 Installation with large quantities of inflammable substances
Installations handling large quantities of inflammable liquids or pressurized gases, where there is a hazard of large escapes, should be kept at such a safe distance from open fires as the local situation demands, taking into account the prevailing direction of the wind. These installations include storage facilities of inflammable liquids and gases.

1.2.3.8 Potential ignition sources
When locating potential ignition sources such as flares, boiler-houses and switching stations with respect to installations where inflammable gases and liquids are present then the information gained from studying the wind rose should be used.

1.2.3.9 Segregating high risk equipment
Equipment presenting a relatively greater risk should to a certain extent be kept separated from other equipment. Stations where extremely reactive substances are mixed, or where very toxic and corrosive substances are processed, and where pyrophoric substances are collected, should be separated from areas where fire hazard, toxicity, corrosivity or reactivity may cause damage.

1.2.3.10 Cooling towers
Cooling towers may cause mist and slipperiness in and outside the fence. Cooling towers should be placed in such a way as to cause the least possible hazard by mist, precipitated mist and frozen patches. The use of aircoolers may be contemplated.

1.2.4 Fire fighting and rescue operations
1.2.4.1 Multiple access to the site
For effective rescue operations in the event of calamities adequate, multiple access to the site from several directions is desirable.

1.2.4.2 Location of mobile fire-fighting material and ambulances
Mobile equipment for fire-fighting and rescue operations should be stationed in a safe place, but in such a way that it can readily be moved to anywhere in the site.
1.2.5 Location of storage and loading facilities
1.2.5.1 Loading facilities, weigh-bridges

Warehouse for the storage of products, loading facilities and weigh-bridges should be positioned in such a way that traffic in the operating area is minimised and can take place over wide roads outside this area.

1.2.5.2 Storage

Storage of raw material, intermediate products and final products in carefully evaluated quantities should be such that dependent on the vulnerability of the packing and the stability, inflammability and toxicity of the product - ample distance is observed within the storage area as well as with respect to production units and buildings.

A combination of substances stored in one storage area should not constitute a greater hazard than each individual substance stored.

1.2.5.3 Large tanks

Large tanks containing inflammable and/or toxic or corrosive substances should be placed in not more than two rows with a view to the accessibility in the event of fire fighting, rescue operations and maintenance.

2. PROCESS MATERIALS

In order to be able to design a safe plant one should be well informed about the properties of the materials that will be processed or produced. This comprises both single and multicomponent systems.

The same is true for ancillaries such as catalysts, media for the transfer of energy, and for products that may come about under abnormal process conditions (e.g. on decomposition). For elementary concepts concerning explosion reference is made to annex 1. In particular the following properties of substances are of interest in this respect.

2.1 PHYSICAL PROPERTIES

2.1.1 Physical properties of solids

Solids

These properties are:
- the temperature at which the solid phase changes into the liquid phase. It is desirable to draw up phase diagrams where necessary;
- the particle size distribution, the moisture content, the minimum explosive concentration and other factors in connection with the possibility of a dust explosion;
- the appearance (flakes, crystals, prills etc.) in connection with the possibility of caking;
- the expansion coefficient (in connection with rupture of the equipment);
- the solubility in the relevant liquid medium in connection with plugging;
- the possibility of static charging.

2.1.2 Physical properties of liquids, including liquefied gases

Liquids, including liquefied gases

These properties are:
- the temperatures at which solidification and boiling phenomena occur, the possibility of under-cooling, and the vapour pressure to temperature relation. It is desirable to draw up phase diagrams where necessary;
- the solubility or miscibility with other substances; in particular with water (fire fighting);
- the viscosity (overheating);
- the density;
- the surface tension;
- the expansion coefficient;
- the possibility of static charging (see publication "Hazards of static electricity in the process industry").
2.1.3 Physical properties of gases

These properties are:
- the expansion coefficient;
- the density with respect to air (ventilation, concentration);
- the solubility in water;
- the Joule-Thomson effect;
- the critical temperature and pressure;
- the possibility of static charging (see publication "Hazards of static electricity in the process industry").

2.2 CHEMICAL PROPERTIES

2.2.1 Direct fire-risk

The following properties are greatly depending on, for instance, the process conditions, the appearance (a.o. particle size), the way and the time in which the energy is supplied. The question which should be asked then and again therefore is whether the available information is applicable as such. Special attention should be paid to:
- the explosion limits and the effect on then by other substances (e.g. by inert gas, oxygen etc.);
- the flashpoint;
- the ignition temperature and energy;
- the possibility of fermentative heating and auto-ignition (i.e. pyrophoric properties).

2.2.2 Reactivity

Special attention should be paid to the behaviour with respect to oxidizing and reducing agents, water including fire water, air, steam, oxygen and materials of construction. This should be studied also at temperatures that might be reached in the process under abnormal conditions. The possibility of hydrate formation should not be overlooked.

2.2.3 Instability

Special consideration should be given to:
- the possibility of formation and the presence of instable compounds such as peroxides, and the possibility of inflammable and/or toxic decomposition products being formed;
- the possibility of auto-ignition or polymerization with strongly exothermal effects under abnormal conditions;
- the causes that may initiate the foregoing processes, such as the sensitivity to temperature, friction and/or shock, the catalytic effect of contaminants, the acidity (pH) and the moisture content.

2.3 TOXICOLOGICAL PROPERTIES

2.3.1 General

Substances can cause poisoning in different ways. After entering the human body irritating-burning effects on the mucous membranes of the respiratory tract and/or digestive tracts may occur, but a change in biological processes of the human body is also possible. With many substances the occurrence of acute poisoning is very much in the limelight in practice. Other substances lead to predominantly chronic poisoning. Some substances have carcinogenic properties. The place where cancer will occur may be dependent on the entrance route of the substance or the place of contact. The extent of toxicity is expressed in concepts as LD 50 and LC 50. Acceptable concentrations are expressed as TLV and RPEL. Consideration should be given to the fact that great differences in individual sensitivity may occur, while also the effect of some substances may be enhanced by the presence of other substances.

2.3.2 Assimilation

Toxic substances may be assimilated via the respiratory tract the skin, wounds or by swallowing. Assimilation through the skin via contaminated clothing is possible for many substances. With some substances the poisoning that has been contracted via the skin does not come to light until later (phenol, hydrogen fluoride).

2.3.3 Solids

Apart from skin contact poisoning can also occur by inhaling fine dust particles. Some substances cause an affection of the lungs (pneumoconiosis); this can be incurable.

2.3.4 Liquids

Liquid absorption can also take place by inhaling droplets. Acids and bases have a burning effect on the skin; solvents will often defatten the skin.

2.3.5 Gases, vapours

Many gases and vapours have an irritating effect on the eyes, causing the secretion of tears. Vapours of solvents often have a narcotic effect.

2.3.6 Radioactivity

When dealing with radioactive substances the type of radiation, the half-life time, the intensity of the radiation, and the exposed part of the body are of interest in connection with radio-toxicity.
2.3.7 Explanation of a few concepts

LD 50 (Lethal Dose 50)
Lethal dose 50 is that dose whereby 50 percent of the experimental animals die within a given time after administering of the material. The lethal dose is mostly expressed in mg/kg bodyweight; the route of dosing and the experimental animal must be stated.

LC 50 (Lethal Concentration 50)
Lethal concentration 50 is that concentration whereby half the number of exposed animals die after a given time; concentration in mg/m³ or ppm; the experimental animal must be stated.

TLV (Threshold Limit Value)
Threshold limit value is the maximum permissible concentration to which workers may be exposed for 8 hours a day and 5 days a week.

EPEL (Emergency Population Exposure Limit)
Emergency public exposure limit is that concentration which can be borne for a given period of time by workers in emergencies for a certain time without inflicting lasting damage to health, but possibly causing temporary nuisance or irritation or intoxication phenomena.

Remark
It should be noted that in this connection the level of the odor threshold with respect to TLV and EPEL is of great significance.

3. REACTIONS, PROCESS CONDITIONS AND DISTURBANCE ANALYSIS

In order to assess whether a production unit complies with all the safety requirements made upon the process industry a disturbance analysis of each unit is to be made. Hereby a step-by-step check is made of what hazards may be encountered in the reactions under the process conditions, and especially under abnormal conditions.

The result of such a disturbance analysis is that quite often a number of problems can be discerned that originate from the process design. In order to solve these problems alterations in process and design may prove to be necessary. Implementation of these alterations can take much time unless a disturbance analysis is carried out at a very early stage.

Since the selection of the process and the raw materials greatly affect the possibility of developing a safe undertaking, the technical staff of the laboratory and the pilot plant should discern the hazards already at an early stage. Before giving shape to the plans to arrive at a production unit (pilot plant, test- or commercial installation) these plans will have to be submitted for discussion to those who afterwards will be charged with the project development, production, maintenance, instrumentation, safety, fire prevention and environmental control.

Apart from improving the safety aspects the performance of a disturbance analysis usually has also additional advantages such as:
- a more reliable process;
- an increased knowledge of the process;
- a better insight into the dependability of the process.

A well-documented disturbance analysis is also of great value for:
- discussions with Government agencies or insurance companies;
- drawing up directions for service and maintenance, and the training of executive staff and operators.

If in connection with the results of a disturbance analysis a process has undergone several alterations it is to be recommended to carry out another, limited disturbance analysis in order to check whether these alterations are acceptable when implemented into the whole constellation.

The following items go further into performing a tentative and a final disturbance analysis.
3.1 REACTIONS

To be able to perform a disturbance analysis for those parts of the installation within which the chemical reactions take place, sufficient data will have to be known with respect to the chemistry and thermodynamics of these reactions. Very important data are:
- the heat development as a result of the desired reactions;
- the mutual dependence of reaction rate and process variables;
- the limits within which the various process variables are to be kept so as to prevent undesirable reactions;
- the chemical and hence thermodynamic consequences of faulty dosage in quantity and/or order of the reactants or ancillaries;
- what thermodynamic effects may be encountered as a result of the occurrence of undesirable reactions which could be initiated by for instance a mechanical failure (pumps, stirring devices etc.), contamination of the raw materials and materials used, and a runaway of process variables beyond the limits necessary for the desired reactions.

3.2 PROCESS CONDITIONS

3.2.1 Normal process conditions prevail when the various values in the process are in agreement with predetermined values for optimal and safe procedures, or do not deviate more from these than by predetermined maximum differences.

3.2.2 Abnormal process conditions prevail when the relevant values get beyond the predetermined limits for optimal and safe procedures.

3.2.3 Process conditions can be static or dynamic. The first group (static) comprises temperature, pressure and composition. The second group (dynamic) comprises temperature course, pressure course, degree of conversion, heat input and output, stirring rate, gravity acceleration \( g \) factor, pumping rate, flow rate etc.

3.2.4 Normal process conditions can also be determined for situations other than routine production, e.g. for starting and stopping the installation.

3.2.5 Whereas process conditions frequently have constant values in continuous processes, normal process conditions in batch processes may be coupled to a predetermined course of the several values (for instance, on the basis of periods of time). In continuous reaction systems the predetermined values may in some cases be a function of production capacity. Some "normal" process conditions are also dependent on atmospheric conditions.

3.3 DISTURBANCE ANALYSIS

3.3.1 Tentative disturbance analysis

3.3.1.1 General

To analyze the consequences of all the situations that might present themselves a tentative disturbance analysis is made of each process unit with the aid of block diagrams. In this analysis it is examined which causes, as mentioned in 3.4 may lead to abnormal conditions (see 3.5), that could initiate critical situations such as fire or explosion (see 3.6).

On the basis of this examination safety measures are laid down, such as instrumental safety systems (see appendix chapter 3), alarm systems, relief systems and interlocking devices, to prevent abnormal conditions and critical situations.

It should be realized that everything associated with process control - hence also the protective systems throughout the design - will have to be considered as a coordinated system.

3.3.1.2 Block diagrams

In the block diagrams the reactions, process conditions, quantities of raw and ancillary materials, catalysts, intermediate and by-products, waste materials (gaseous, solid or liquid) are mentioned wherever possible. In the tentative disturbance analysis one finds out which data on the substances (see chapter 2) and process conditions additional information is needed to enable assessment of the hazards.

With the aid of the results obtained one arrives at the design of the installation that is subject again to disturbance analysis.

3.3.2 Final disturbance analysis

For the final disturbance analysis the following information should be available:
- a. A list of process materials with relevant data (see chapter 2).
- b. A description of the process with material and heat balances and a process flow sheet.
- c. A floor-plan with the location of the various units (see chapter 1) and/or maquettes.
- d. Piping schemes and/or maquettes.
- e. A drawing with the hazard classification in terms of possible ignition sources subdivided into:
  - electrical ignition sources;
  - all other ignition sources (furnaces, steampipes etc.);
- f. Data concerning the energy supply and its reliability.
- g. The process and instrumentation diagrams.
The following data should be supplied with these schemes:
- the quantities, pressures and temperatures of the media present under normal process conditions;
- the piping including the accessories and tracing with diameter, material, pressure classes and temperature classes;
- the safety devices, type (spring, weight, balanced, bursting disc etc.), set-pressure, capacity, the temperature up- and downstream the device, the way and location of discharge;
- the mechanical protection systems, for instance in the shape of interlocked valves;
- the pieces of equipment with the design pressure and design temperature, the maximum working pressure to be expected, the construction material, the working temperature, the dimensions, the corrosion and erosion allowance of the material, the insulation and the finish (see chapter 4);
- the pumps, the compressors and much alike with the design pressure and maximum working pressure to be expected, the construction material, the design temperature and maximum working temperature to be expected, the pumping head, capacity, type of sealing, type of drive (turbine, electric motor etc.) and type of pump;
- the remaining pieces of equipment with moving parts in connection with among other things the effect of the moving parts on the medium: the type, drive, material and the way of sealing (see chapter 4);
- the measuring and control equipment, impulse lines, control characteristic, capacity, alarm system and the actions on impulse failure.

3.4 CAUSES OF ABNORMAL CONDITIONS

Abnormal conditions can result from many factors, such as:
- disturbances in the supply, discharge and circulation of process materials/flows;
- disturbances in the energy supply such as electric power, water, steam, air, fuel etc.;
- disturbance in the measuring and control equipment and the computer;
- the starting-up or shut-down of a process;
- maintenance activities;
- faulty actions, e.g. blocking in;
- fouling, corrosion and erosion;
- fire in the neighbourhood;
- meteorological effects such as lightning, gale, frost, etc.;
- fermentative heating;
- static electricity;
- failing equipment, accessories, packings etc.;
- animals (a beetle in an alarm device, short-circuiting in high tension installation by rats).

3.5 ABNORMAL CONDITIONS

The following conditions are examples of what may be considered abnormal:
- leakages, whereby substances escape or leak from the outside to the inside, as well as internal leakages from one compartment to another, for instance leaking pipes in an apparatus;
- a change in the proportion of reactants;
- interruption of the mixing or separation process by a failing mixer or a blocked separator;
- a change in temperature and/or pressure (a small change may initiate big effects);
- contamination of the reacting substances or flows (small amounts of air or other substances may have a catalytic effect);
- undesirable reactions such as polymerization and decomposition;
- overfilling;
- blockage;
- undesirable backflow;
- loss of communication.

3.6 CRITICAL SITUATIONS

It should be investigated whether abnormal conditions could lead to critical situations. A critical situation may be present when there is an acute risk of rupture of equipment or piping, leakage etc.

This may result in, for instance:
- a. Fire and/or explosion or implosion.
- b. Escapes of hazardous substances present or formed during the escape.
- c. Escapes of hot or very cold substances.
- d. Development of noise, smoke, mist etc.
- e. Escalation of the points mentioned in a. through d.
4. EQUIPMENT (including piping and accessories)

4.1 INTRODUCTION

The hazards associated with the use of equipment can be twofold. Failing construction material of the equipment can give rise to a hazardous situation, but also the function and design of certain equipment may involve danger for the immediate surroundings. In order to gain a better insight into the possibilities which may lead to the failing of equipment it is necessary to carry out disturbance analyses as described in chapter 3. The hazards associated with equipment can often be warded off by fitting safety devices, by correct design and proper use. In order to avoid unsafe situations all equipment should be checked on which requirements should apply with respect to design, choice of material, construction, installation and special provisions.

As for the prevention of explosion hazards reference is made to annex "Explosion Prevention".

4.2 DESIGN

4.2.1 Explosion

If explosive conditions cannot be avoided in the equipment it deserves consideration to choose the design such that the explosion pressure can be withstood. In many cases explosionproof design is preferable, primarily for the protection of the surroundings. If for technical or economic reasons this cannot be realized another solution can be found by applying bursting panels, explosion doors, or weak seams.

If one of these alternative solutions is applied the restriction holds that in the design the location of the equipment the hazards resulting from the operation of these safety are taken into account. These hazards may be, for instance, ejection of an explosion door or ejection of a flame, or of undesirable substances.

4.2.2 Ignition sources

Attention should be paid to avoiding as much as possible the application of moving parts which by friction or impact may give cause to the development of sufficient ignition energy in an explosive/inflammable atmosphere, both inside or outside the equipment. Catching foreign material that is capable of spark formation is a necessity in this connection. Ignition resulting from discharge of static electricity should also be prevented. It should also be borne in mind that spark formation may occur in electric equipment. Contact between hot surfaces and substances having a low ignition temperature should be avoided as much as possible.

4.2.3 Pressure differences

Attention should be paid to the hazard that may occur when a high pressure system is connected with a system of lower pressure via a control valve, a reducing valve or a by-pass (e.g. round a reducing valve, control valve, a unit etc.). In the aforementioned cases the low pressure system should be able to stand up against the same pressure as the high pressure system, or should be protected by a safety device. In this connexion attention is drawn to the hazards of complicated combined blow off systems that can be closed, and to the hazards of those systems, whereby safety valves blow off into a system of lower pressure (so-called "silent blow off"). Need should also be given to the possibility of thermal expansion as a result of the heat of the sun, steamtracing, and possible consequences of this, for instance, when blocking in a cooling liquid in a heat exchanger or when blocking in pipe sections.

4.2.4 Leakages

If there is a reasonable chance that a separating wall will fail then attention should be paid to the possibility of a excessive pressure rise on the low pressure side due to the large pressure difference with the high pressure space, in case of leakage. When processing dangerous substances special attention should be paid to the sealing of rotating parts such as pumps, stirrers etc., in particular when high pressures are involved. Double mechanical seals may then be imperative. The seal may be purged from outside by an inert substance under a pressure than the internal pressure. In case of leakage it to atmosphere no hazard is created.

4.2.5 Plugging

It is also possible that plugging of the equipment takes place due to the nature or constitution of the medium being processed, which may result in a too high pressure. The shape of certain parts of the equipment may play an important role in this respect.

4.2.6 Pump capacity and breathing

When designing breathing and venting systems the maximum pump capacity and possible weather effects should be taken into account.

4.2.7 Vacuum

When designing equipment attention should
also be paid to the possible occurrence of vacuum as a result of:
- condensing steam in a closed space
- an insufficiently vented space
- the sucking action of a pump or a compressor etc.

Designing various types of equipment for complete vacuum is to be recommended in many cases.

4.3 CHOICE OF MATERIAL

When selecting the material for the equipment consideration should be given to the following:

4.3.1 Corrosion and erosion

When selecting the material consideration should be given to the possibility of corrosion by the substances present, the possibility of erosion by solid and liquid particles, and a possible combination of these two.

Besides attack and weakening of the material on the spot itself, corrosion can also cause difficulties at a distance, for instance by blocking tubes and equipment owing to the accumulation of corrosion products. Also other forms of corrosion, such as stress corrosion, hydrogen corrosion, intercrystalline and transcrystalline corrosion etc., should be considered, as well as corrosion from the outside (especially underneath the insulation) and corrosion by wandering currents in the case of underground piping. In this connection the possibility of cathodic protection is pointed out.

4.3.2 Chemical effects

When selecting the material of construction the possible occurrence of catalytic effects of the material on the medium and vice versa should be investigated.

4.3.3 Resistance

When selecting the material consideration should be given to the resistance of the material (including synthetic- and packing materials) with respect to the medium (attack, solution, hardening, swelling, deformation etc.), vibrations, anticipated wear, and process conditions.

4.3.4 Temperature and temperature fluctuations

When selecting the material consideration should be given to the normal process temperatures as well as to the maximum and minimum possible temperatures occurring as a result of disturbances or under the influence of weather conditions.

One should not forget the possible changes in the structure of the material resulting from large and frequent temperature fluctuations.

4.3.5 Pressure and pressure fluctuations

When selecting the material attention should be paid to the working pressure as well as to the maximum possible pressures occurring as a result of disturbances.

One should also keep one's mind open to the occurrence of frequent pressure fluctuations, vibrations, and the low cycle fatigue of steel types with high yield stress.

4.3.6 Spark formation

When selecting the material consideration should be given to spark formation owing to friction or impact, especially when applying materials of different hardness. If necessary, sparkless materials should be applied for e.g. rotating parts, hose couplings etc.

4.3.7 Static electricity

When selecting the material for V-belts, hoses, filter bags etc. consideration should be given to the desirability of applying materials of sufficient electric conductivity.

4.3.8 Insulation

If insulating material is filled in loosely one should keep one's mind open to the possibility of this material getting into the equipment.

When selecting the insulating material consideration should be given to the possibility of ignition via the insulating material, its absorption of inflammable liquids, and the development of a so-called "cold bridge".

4.4 CONSTRUCTION

The following should be taken into account when constructing the equipment.

4.4.1 Meteor-effects

During construction of the equipment consideration should be given to the critical wind velocity in respect of resonance, snow and wind load, lightning etc.

4.4.2 Grounding and bridging

Attention must be paid to the possible occurrence of static electricity. To prevent energetic discharges in an explosive/combustible medium, equipment, parts and pipes should be electrically earthed or bonded.

4.4.3 Vibrations

The possibility of vibrations which may cause fracture should be checked.

Mechanical vibrations mainly occur in and near equipment with moving parts (e.g. pumps, compressors, stirrers etc.).
CHECK-LIST

Vibrations can also be caused by appreciable velocity variations that may result from the operation of safety valves, control valves etc. The own frequencies of equipment, pipework and buildings may amplify these vibrations. For high-frequency vibrations see 4.4.5.

4.4.4 Stresses

Possible stresses resulting from expansion, contraction or the weight of the pipeline and the product (expansion bends, expansion bellows, flexible couplings and stayings) need careful study. These stresses often become manifest near flange connections and branch connections on equipment and may result in fracture. Also stresses resulting from reaction forces may become apparent for instance when blowing off via safety valves that have not been adequately mounted or supported.

4.4.5 Noise

Production and propagation of noise should be prevented if they do damage to the auditory organs, interfere with communication, or deteriorate the physical and psychical conditions. For the prevention of noise the construction and design of potential sources are of importance (e.g. gear-boxes, compressors, ventilators, shaping of pipes, and the presence of reducing devices). Total or acoustic enclosure should be considered (see also 4.5.6).

4.4.6 Sealing

Generally speaking, the number of seals should be minimized. The construction of the seals should fit in with the system. In this connection the following deserves attention:
- seals should be effectively contained;
- temperature and pressure fluctuations should be met efficiently;
- the use of, for instance, mechanical seals may sometimes be an adequate solution. In case of rotating parts mechanical seals have the drawback that skillful fitting is necessary, and that a leak may increase rapidly;
- stuffing-box packings for non-rotating parts are satisfactory in general, because in case of leakage this will be insignificant initially, and maintenance is easy;
- if cooling is necessary the coolant should be chemically inert with respect to the medium;
- if hazardous substances are used the application of a seal liquid may be considered;
- with gas compressors constant supply of seal liquid should be ensured; also an alarm in case of interruption of the supply could be considered;
- the use of immersion pumps.

4.4.7 Hoisting facilities

The necessity/desirability should be studied to provide the possibility of safe dismantling and transport by fitting special provisions such as e.g. hoisting lugs, by installing fixed hoisting equipment in appropriate places etc.

4.5 LOCATION OF EQUIPMENT

When the location of equipment is determined, following points need attention:

4.5.1 Detonation and decomposition

If it is not possible to prevent a rapid decomposition, a homogeneous explosion and/or a detonation at all times, this possibility cannot be circumvented in the design then erection in suitable bunkers should be considered.

4.5.2 Consequences of fire and explosion

Equipment constituting an increased risk should be set-up in such a place as to cause the least possible secondary damage in case of an incident.

4.5.3 Leakage and spillage

The construction of trays, sumps, bunds etc. to collect and remove the substances should be considered. Inflammable and hazardous substances in those places where they can regularly be drained off (e.g. when draining, sampling etc.) should be collected in a closed system in such a way that they cannot spread over floors or in the atmosphere. In special cases such as for instance using chlorine and phosgene a safe removal of the gases to a disposal system should be provided.

4.5.4 Accessibility

Good accessibility that operations, is essential to ensure that inspection, maintenance, repair and fire-fighting can be carried out unimpeded. Also adequate facilities for entering equipment should be present, such as platforms, stairs, manholes etc.

4.5.5 Protection of personal

The occurrence of injuries as a consequence of touching hot pipes, falling and bumping should be minimised. Fitting bare pipes that will be heated within reach, and placing valves, piping and other parts of equipment at head level or inside the gangways are to
be avoided; if this is not possible then adequate padding should be applied.

4.5.6 Noise

Bothersome and offensive sound that can propagate and be amplified via pipework, buildings or construction parts, even if the source is acoustically enclosed, is to be prevented.

The following measures may serve to abate noise:
- installation of noise sources on resilient mounting systems;
- complete insulation and acoustic enclosure of energetic sound sources by isolated installation outside buildings, and fitting flexible pipe-sections between noise sources and connected piping;
- no or absorbing contact between pipes, walls, floors etc.

4.5.7 Stresses

Care should be taken that no undesirable stresses will occur when pipework is mounted. Ample facilities should be provided for expansion or contraction when the temperature increases or decreases.

The pipes should be well aligned so as to prevent forcing them when they are being connected since this might give rise to stresses.

4.6 SPECIAL PROVISIONS

In addition to the necessary protection of equipment against overheating, overpressurizing, overfilling etc. (see annex chapter 3), attention should be paid to the following.

4.6.1 Energy interruption

In most cases it is undesirable if electrically driven equipment is automatically set in operation as soon as power supply is resumed.

When power supply is interrupted there must be a possibility to switch over to another energy supply for vital parts of the equipment.

Where necessary delay systems should be incorporated to prevent unnecessary shut-downs in case of very short interruptions.

4.6.2 Explosion prevention

Explosive reactions can sometimes be prevented by:
- additional cooling
- adding inert gases
- adding catalyst poison
- eliminating ignition sources.

At an early stage these reactions can sometimes be stopped by a suppression system.

4.6.3 Detection equipment

It deserves consideration to investigate where and to what extent the application of detection equipment to signalize inflammable or explosive mixtures and the presence of toxic substances is useful or necessary.

The same goes for the detection of overheating of equipment by e.g. infrared, colour changing paint, etc.

4.6.4 Flame arrestors

In places where flashback may occur flame arresting devices are to be used.

4.6.5 Spark arrestors

Spark arrestors are to be used in those places where sparks may constitute a hazard (e.g. on exhausts of internal combustion engines).

4.6.6 Freezing and solidifying hazards

Measures should be taken to prevent undesirable solidifications and freezing.

4.6.7 Codes

Identification of piping, valves etc., and the use of safety symbols in appropriate places is strongly recommended.
5 THE STORAGE AND HANDLING OF DANGEROUS SUBSTANCES

5.1 THE STORAGE OF DANGEROUS SUBSTANCES

The conditions laid down with respect to the safe storage of dangerous substances take into account the nature and quantities of the substances. Dangerous substances may be stored in drums, cylinders or tanks. A number of fundamental aspects of storage, however, mean that there are certain subjects to which attention must be devoted in the storage of dangerous substances irrespective of their nature and the way in which they are stored. The kind of measures which such considerations will call for, however, will depend entirely upon the actual type of storage in question and will differ accordingly. This section will attempt as far as possible to give the essential points only.

5.1.1 The danger

5.1.1.1 Nature of the danger

One of the first points which one must establish is the nature of the danger. This may be:
- flammability
- explosiveness
- reactivity
- radioactivity
- stability
- toxicity
- possible fire-promoting properties (see also Section 2).

5.1.1.2 Size of storage unit

The nature of the danger and the scale of storage together determine the size of the theoretical danger. The first question therefore must be what is the total maximum permissible amount that may be stored. This applies equally well to a tank farm for liquids, consignments of drums, and the storage of cylinders, for example, of gas. This principle even applies to the bulk storage of solids; the sort of point to consider in such cases is the size of the bays and/or sheds. The size of the danger is also dependent on the distance from the centres of population, public roads etc. Generally speaking centralization of the storage of dangerous substances is a help when it comes to providing the necessary facilities, but consideration must be given in connection with what has just been said, to the establishment of limits for the maximum total amount to be stored in any one area.

5.1.2 Storage possibilities

5.1.2.1 Form of storage

In certain situations it is possible to make a choice from various different forms of storage each having its attendant risks. Liquified gases for example may be stored under pressure or at low temperature under atmospheric pressure; flammable liquids in ground-level tanks, underground tanks or in tanks on mounds.

5.1.2.2 Choice of storage

The form of storage selected will depend on the potential danger, the distances listed under 5.1.1.2 and the risk of an incident.

5.1.3 Precautions

5.1.3.1 General precautions

In order in the first place to prevent incidents and, secondly, in the event of an incident to be able to act swiftly, attention must be devoted to a number of general precautions e.g.:
- more than one point of access to the storage areas, rooms or sheds
- roads and gangways between the tank pits, tanks, piles, pallets, piles of sacks etc.
- of adequate width
- good accessibility to the storage units, e.g. not more than two rows of tanks in a tank pit
- adequate lighting of storage sites, in sheds and stores etc.
- good communications with other locations on site (telephone, alarm system)
- good ventilation of storage sheds; in the case of storage of flammable substances, forced draught is sometimes necessary (on account of vapour densities)
- avoidance of storage of substances that react with each other in adjacent tanks.

CHECK-LIST

5.1.1.3 Distances

The size of the danger will determine the effect on the immediate environment in the event of an incident. On this in turn will depend the appropriate selection of distances, relevant considerations being:
- distances between the storage units themselves
- distances from storage units to parts of the plant
- distances from storage units to loading points
- distances from storage units to site roads and railways
- distances from storage units to site limits
- distances from storage units to office buildings
- distances from storage units to centres of population and public roads.

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5.2 THE HANDLING OF DANGEROUS SUBSTANCES

At points where lines and hoses have to be coupled to transportable tanks, which during loading and discharge are often open to atmosphere, the risk of leakage of dangerous liquids, vapours and gases is present to a more serious extent. The location of the installation, the installation itself, safety precautions and operating procedures must take into account the greater hazard.

5.2.1 Selection of the loading site

5.2.1.1 Surroundings

Under normal handling procedures, and even in the event of a serious leakage, any substances released may not form an inadmissible hazard for the surroundings. On the other hand, the surroundings (furnaces, rail and road traffic in the vicinity) may not form an unacceptable hazard for the loading operations.

5.2.1.2 Distance

The distance between the loading site and the storage site must at least comply with the pertaining guidelines and regulations.

5.2.2 Roads and railways (see also Section 1)

5.2.2.1 Access roads

The loading site access roads must be so routed that they avoid the other danger zones of the plant.

5.2.2.2 Traffic density

The traffic density in the vicinity of the loading site must be kept to a minimum.

5.2.2.3 Level location

Roads and railways must be perfectly level where vehicles and rolling-stock await loading, to avoid the risk that cars start moving inadvertedly.

5.2.2.4 Obstruction

Ample facilities for manoeuvring, shunting and parking must be provided. Railway loading sites must be so arranged that roads are never blocked as a result of shunting or waiting.

5.2.2.5 Siting near buildings

Weighbridges, administrative sections (dispatch offices), queueing and parking facilities must be so laid out as to promote swift and safe completion of the loading procedures.

5.2.3 Methods of loading and unloading

The selection of the product-handling system depends on the properties of the substance. The following factors should be taken into account:
- the properties of the substance to be loaded (see Section 2, process substances)
- the risk of the formation of explosive mixtures of vapour and/or dust and air, and ways of preventing this
- the degree to which the escape of liquids, gases and vapours must be prevented (use of closed systems)

5.1.3.2 Special precautions

Depending on the nature of the substances stored special precautions are sometimes necessary. Consideration should be given to:
- the effect of temperature on reactive substances (protective measures against directly radiated heat)
- the effect of the presence of air in contact with highly flammable or reactive substances may necessitate the use of an inert atmosphere (a blanket of nitrogen or carbon dioxide)
- where flammable substances are stored in spherical tanks or saddle tanks, consideration must be given to whether or not it is necessary to make the ground slope and provide a system for trapping any liquid that leaks
- where liquefied toxic gases are stored, measures to enable swift action to be taken in the event of major leakages in order to minimize evaporation (collection systems, foam systems)
- where dangerous liquids or gases are stored, the discharge capacity of safety valves should be such that the vapours resulting from the heat flux of a nearby fire can be relieved
- the location of the vent to atmosphere of safety valves and locations where the liquids or gases can be destroyed if necessary. The more so in the case of toxic liquids and gases
- precautions in the case of storage of dangerous liquids or gases to prevent overfilling of containers
- the use of flame-arrestors in the storage of flammable liquids or gases. (Flame-arrestors are often removed in winter)

The installation of permanent firefighting equipment should also be considered (sprinkler systems, foam or halogen firefighting systems). In the case of larger tanks, the use of a floating roof or some system of reducing evaporation must be considered. Where flammable substances are concerned, the sizing of the drainage system of the area round the storage site (e.g. the tank pit) must also be based on the capacity of the available firefighting and/or cooling system.
5.2.4 The design of the loading site

5.2.4.1 Accessibility

Good accessibility to rail- and road tank cars, and ships by way of, loading stages, ramps and docks with suitable escape routes is a must. In the case of ships, two points of access should always be provided.

5.2.4.2 Leakages

Facilities must be provided for catching and safely draining away leaking liquids and/or rendering them harmless.

5.2.4.3 Discharge

Provisions must be made for discharging the cargo of a transport tank both in part and in whole (e.g. in the case of overfilling or a returned off-specification product).

5.2.4.4 Equipment

Lines, pumps and other equipment must be located such that the risk of damage from collisions is excluded, or alternatively, other measures must be taken to prevent such accidents.

5.2.4.5 Loading bays

Loading bays must be clearly marked and wheel chocks and brake drags must be available.

5.2.4.6 Earthing

Adequate equipment must be available for earthing transport units and other equipment.

5.2.4.7 Communications

Provisions must be made for adequate communication between the operating personnel.

5.2.4.8 Lighting

Adequate lighting (including emergency lighting) must be provided.

5.2.4.9 Protective clothing etc. and firefighting equipment

Suitable personal protective clothing and equipment, emergency showers and firefighting equipment must be provided in sufficient quantities and at strategic points, so arranged that they can be reached at all times irrespective of the direction of the wind.

5.2.5 Pumps, lines and ancillary equipment

5.2.5.1 Flow rate

For the establishment of pump capacities and line diameters and also in the use of filters and other ancillary equipment, the most important factor is the safe flow rate to prevent dangerous levels of electrostatic charging when handling low electro-conductivity liquids.

5.2.5.2 Safe distance

Pumps and ancillary equipment should preferably be fitted in rigidly mounted pipe sections and at a safe distance from the loading point, but at the same time be easily accessible. It is also desirable to fit an emergency cut-off valve that can be operated from a safe distance, and also to fit an emergency stop system on the pumps.

5.2.5.3 Lines

Solid lines are preferred. Where the use of hoses is essential these should be:
- inspected and approved
- capable of withstanding the highest possible operating pressure
- suitable for the substance to be handled.

Regular replacement of the hoses should be considered. Provisions must be made to prevent hoses and couplings from being dragged along the ground in view of the risk of sparks and to avoid damage and contamination.

5.2.5.4 Couplings

An adequate stock of adaptors and couplings must be available so that a safe connection can always be made.

5.2.5.5 Uncoupling

Provisions must be made for depressurizing delivery lines and hoses and letting them drain before they are uncoupled.

5.2.6 Safety devices and interlocks

5.2.6.1 Overfilling

In cases where filling to above the maximum allowable level could give rise to critical situations, two independent filling control systems must be provided. One of these being a continuous measurement made by a calibrated method. The prime purpose of measurements made during filling is to prevent overfilling (in certain cases measurement by means of weighing may be appropriate). Linking the measuring device to an automatic cut-off mechanism will reduce the chance of overfilling.
7. CIVIL ENGINEERING ASPECTS

In the design, building and maintenance of plant installations attention must be devoted from the point of view of safety to the following civil engineering aspects (see also section 1).

7.1 THE GROUND

7.1.1 Soil structure

It is common knowledge that different types of soil have different properties. Alternating stress patterns, compressive strength, sloughing, permeability and vibrations can all affect the bearing capacity of the soil.

7.1.2 Soil conditions

Well before the design of a plant installation, thorough soil tests must be made to establish the character of the ground and its mechanical properties and hence its bearing capacity.

7.1.3 Acidity

A test must be made to establish the acidity of the soil in view of the possibility of attack of the foundations, cables, pipes and underground tanks etc.

7.1.4 Ground movements

In addition to natural settlement, regular or irregular settlement resulting from water extraction, infill, old rubbish dumps, old creeks and dikes etc. must be taken into account. Attention must also be devoted to existing or expected subsidence caused by mining, natural gas production, salt extraction and the geological structure.

7.1.5 The ground surface

At points where leakage can be expected the ground must be duly treated if necessary.

7.1.6 The water table

Variations in the water table, including long-term variations, must also be taken into account.

7.2 FOUNDATIONS

7.2.1 Soil tests

The results of the soil tests along with the static and dynamic loads to be expected must be taken into account in the design of the foundations. Inadequate foundations can result in the fracture of lines and uneven settling of equipment, installations and tanks.
7.2.2 Natural frequencies
In the case of the foundation of machines, care must be taken to ensure that the natural frequency of the spring mass system of the piles does not coincide with that of the machine.

7.2.3 Flow slide
Allowance must be made for the increased settlement of the foundations as a result of vibrations (flow slide).

7.2.4 Viscosity changes
Allowance must be made for the increased settlement of friction piling as a result of viscosity changes in the ground caused by vibrations.

7.2.5 Unwanted vibrations
The foundations and mountings of machines giving rise to vibrations must be so designed as to transmit the least possible vibration. Unwanted vibrations caused by pile-driving activities in the vicinity of installations must be avoided and there are a number of special methods that can be employed in such cases.

7.2.6 Tank foundations
The bearing capacity of the sub-soil in the case of tank foundations must be consistent beneath the whole foundation in order to prevent uneven settlement. The composition of a tank foundation must be such as to prevent attack and weakening of the base. The sloping face of the foundation to the surrounding area must be given a waterproof revetment so that rainwater dripping off the tanks cannot weaken the foundations. A certain amount of even settlement of a tank is tolerable provided that this is taken into account in the design of the pipe work.

7.3 DRAINAGE SYSTEMS
Depending on the substances to be removed, drainage systems are potential sources of danger because of the possibility of the formation and distribution of explosive gas and air mixtures. Dangerous substances can also be transported via sewers to parts of the site at which the necessary safety precautions relating to dangerous substances are not taken. The general drainage scheme and the detail design of the civil engineering aspects thereof must therefore not only take account of the capacity and construction materials etc. of the system but also of the possibility of the formation of explosive gas and air mixtures.

A distinction can be drawn between sewers according to function; whether they are for the removal of:
- rainwater and other meteoric water
- cooling water
- chemically polluted water
- oil-polluted water
- domestic waste water.

The function in turn will determine the choice of design:
- open drains
- half-full drains
- flooded drains.

7.3.1 Junctions
At the junction between two different drains, suitable precautions must be taken to ensure that there can be no movement from the section of sewer carrying the most dangerous medium to the less hazardous section. Adequate precautions must also be taken at such junctions to deal with the possibility of liberation of dangerous vapours. Where different sorts of waste water come into contact care must be taken to ensure that no undesired reactions can take place.

7.3.2 Capacity
The capacity of the sewer must be matched to the maximum rainfall rate (in the Netherlands 25 mm/hour) or the maximum volume of fire water, which ever is the greater. The maximum volume of fire water being the water from permanent firefighting and cooling systems plus water from mobile units. Allowance must also be made for blockage of drains by pieces of insulation and other materials that could get carried into the drainage system as a result of firefighting operations.

7.3.3 Materials
The construction material of sewer pipes must be appropriate for the properties and condition of the media to be removed.

7.3.4 Flexible connections
Connections from process plant on a firm base to unsupported drainage systems must be flexible enough to prevent fractures.

7.3.5 Mechanical loading
Where drains are subject to mechanical load (under roads), adequate measures must be taken to protect them.

7.4 ROADS

7.4.1 Roads system
See Section 1 for details of the road system. The road system should be laid out with a view to ensuring ready access by fire appliances, ambulances etc. to the scene of an accident.
7.4.2 Materials

In the selection of surfacing materials for the loading site possible reactions of spilled substances (liquid oxygen) with the road surface must be taken into account. Allowance must also be made for other forms of attack.

7.4.3 Road construction

The roads must be designed for a maximum permissible load that is high enough for all normal traffic including fire appliances etc. The maximum permissible loads on bridge, syphon crossings and jetties must be clearly indicated; vulnerable spots must be protected (guard rails etc.).

7.5 BUILDINGS (see also Section 9)

7.5.1 Internal arrangements

The internal arrangements of a building must take into account the hazards of fire and explosions and the possible presence of asphyxiant or toxic substances. This is particularly applicable to modifications of production facilities especially in the case of existing areas that were not originally designed for such purposes. Factories and work places are often subject to various acts and the buildings must therefore comply with these. In many countries the plans must be submitted to various government bodies for approval.

7.5.2 Materials

The materials used must be both chemically and physically as resistant as possible to weathering and any substances released into the atmosphere, or must be adequately protected. The harmful effects of the products of chemical compounds released from the building materials used or other substances present as a result of fire, must also be taken into account.

7.5.3 Construction

The method of attachment of cladding, windows and the like requires special attention in view of the high wind loads that can be expected. Processes involving an explosion hazard should generally be carried out in a safe place in the open air or in bunkers. Where, under normal circumstances, there is a risk of explosion outside pieces of equipment but within a building, the building must be suitably designed to reduce the violence of such an explosion (e.g. collapsible walls and a light roof structure). Where the explosion force can be expected from outside, the appropriate design features must also be incorporated. The vacuum that occurs after an explosion sometimes does more damage than the initial pressure wave.

7.5.4 Ventilation

Where ventilation is provided by drawing in outside air a system should be provided for stopping the draught in the case of, for example, a gas alarm outside the building. Where gas detection equipment is provided it can be linked automatically to the ventilation system cut-off. Other measures may be necessary where special filters are fitted in the air inlet. Where there is a risk of an explosive mixture in an extraction system any source of ignition in the system must be avoided. The capacity of a ventilation system must be such that the formation of explosive mixtures or concentrations harmful to health is prevented, or that if such situations do arise, they are quickly corrected.

7.6 ADDITIONAL POINTS RELATING TO INSTALLATIONS

7.6.1 Design

In addition to the strength requirements of the structure to meet static loads, allowance must also be made for the effects of dynamic loads like vibrations, expansion and contraction due to temperature changes, and possible explosions. In the case of very large dimension like large tanks, checks must be made to establish whether the foundations will take the extra forces due to low pressure on the leeward side in strong winds. The static load to be used for design purposes must where necessary be based on equipment filled with liquid if for inspection purposes for example such equipment is in fact filled with liquid although under normal operating conditions it contains gas.

7.6.2 Floors, platforms and stairways

The ways up to operating platforms and work floors must be safe to use, viz. vertical ladders, for example, should be caged-in and their length should be kept to a minimum. Floors, platforms and treads of stairs must be anti-slip. Where there is considerable danger of fire or aggressive substances, it may be advisable locally to use closed floors. Catwalks between distillation columns and the like may not be so stiff that they affect the stability of the installations.
8. DIVISION OF SITES IN AREAS

8.1 Although a plant should be so designed as to render it impossible for inflammable substances to escape from the equipment into the open air, this possibility can never be completely ruled out.

In order to reduce the chance of a fire or explosion in such cases the possibility of ignition of an inflammable gas/air mixture should be minimized; the location of ignition sources plays an important part in this respect.

In areas where an inflammable gas/air mixture may be encountered a great deal of attention should be paid to the design of electrical installations.

8.2 To enable the optimal assessment of the necessary special provisions for electric installations respectively to enable the right choice of electric equipment suitable for this application - hazardous areas for gases and vapours are divided in zones that are closely related to the degree of probability to which an explosive gas mixture may be present.

8.3 In sequence of decreasing probability of an explosive mixture in hazardous areas the following zones are distinguished.

Zone 0
An area within which an explosive gas mixture is present permanently or for prolonged periods.

Zone 1
An area within which the probability of an explosive gas mixture is high under normal operating conditions.

Zone 2
An area (only under abnormal operating conditions) in which the probability of an explosive gas mixture is low, and in which such a mixture, if present, will only exist for a short time.

Unclassified zone
An area not covered by the foregoing zones.

8.4 In view of the significance of a justifiable division into areas with regard to electric equipment reference is made to the various national and international codes.

9. FIRE PROTECTION

9.1 INTRODUCTION

Fire protection consists, on the one hand, of measures to prevent the occurrence and, on the other hand, of measures to effectively fight the fire once it has started.

Fire prevention measures include specially designed features in buildings and plants, efficient detection and alarm systems and thorough training of staff, etc. Control measures include fire brigades, firefighting equipment, automatic and non-automatic extinguisher systems, etc. Before implementing fire prevention measures it is advisable to become fully acquainted with the existing situation, the current standards and the possible consequences of fire in the area in question. In some cases a careful study can provide optimum security by simplifying or reducing the number of systems to be used and/or rationalizing the firefighting organisation. The following measures may be mentioned in this context:

- interconnection of fire-water systems;
- the utilization of existing emergency power supplies;
- maintaining of a central store of extinguishing equipment.

A thorough knowledge of the local situation is equally essential for the drafting of action plans and a disaster contingency plan (see section 10).

9.2 FIRE PROTECTION OF BUILDINGS AND/OR PLANTS

9.2.1 Fire prevention

Attention should be given to the following points which are important for fire prevention:

- the flammability of the construction materials, taking into account the possible absorption of process materials;
- the materials to be used in places where generation of sparks has to be avoided or is undesirable (for example, prohibition of the use of aluminium paint on steel, permanent electrical conductivity of floors);
- the design and location of ducts for smoke or combustion gases;
- the installation of heating systems;
- the installation and design of electrical systems;
- the locating of gas storage and distribution systems;
- the provision of adequate ventilation, which may result in underpressure or over-pressure;
- protection against lightning.

9.2.2 Personnel safety

In order to prevent or minimize personal
accidents in the event of fire, allowance should be made for:
- the number, location and dimensions of exits and emergency exits from rooms in the building and from the building itself, which should be adequate for the number of people involved.
- Allowance must be made for the fire risk of each room;
- the avoidance of dead-ends in corridors or galleries;
- the correct type, location and swing of doors;
- the non-slip qualities of floors and stairways and the strength of handrails;
- the clear indication of emergency escape routes and provision of emergency lighting;
- the materials used for emergency escape routes, as regards their flammability and/or their ability to generate smoke and toxic decomposition products.

9.2.3 Restricting the spread of fire

The spread of fire can be reduced by:
- division into compartments, both horizontal and vertical, making due allowance for the routing of pipework, air and ventilation ducts, transport facilities, stairways, lifts, expansion joints, etc.
- Partition walls should be designed to prevent penetration by fire;
- dividing long escape routes into sections by fitting fire doors, smoke traps, etc.
- fitting liquid-retaining sills or sumps which empty quickly and safely;
- fitting ventilation shafts with baffles which close automatically in the event of fire;
- providing for remote control of the ventilation system from a safe place;
- adopting measures to prevent the propagation of fire to other buildings or plants. Some ways in which this can be achieved are:
- fitting fire doors or sprinkler curtains at both ends of essential bridges, connecting tunnels, chutes, conveyor belts, pipe ducts, etc.;
- fitting wire-reinforced windows;
- fitting fireproof material or fire walls; protecting roofs against fire (sparks), etc.

In addition to these measures, fire damage can be minimized by:
- covering load-bearing members with fireproof, heat-insulating materials;
- internal water-cooling of hollow load-bearing structures;
- installing sprinkler systems, water screens, static firefighting systems, etc.;
- providing adequate facilities for draining fire water;
- minimizing smoke damage by fitting smoke vents in stairways, sheds, working areas, etc. The smoke vents must be fitted at the correct locations and it must be possible to open them in case of fire.

9.3 FIRE FIGHTING ORGANIZATION

The fire fighting organization must be adapted to suit the nature and extent of the risk. Effective co-operation between the own organization and the external auxiliary organizations is essential for effective fire fighting.

9.3.1 Task of the organization

The task of the own fire fighting organization is to fight the fire from start to finish, or at least during the time between the detection of the fire and the arrival of the external auxiliary services.

9.3.2 Manpower

Both the manpower and the stock of firefighting equipment available to the own fire service must be related to the nature of the risk and the firefighting equipment already provided in the area in question. A sufficient number of trained personnel should be present at all times, depending on the shift system worked at the plant.

9.3.3 Composition

The fire service personnel should be selected such that people with an expert knowledge of plant operations are available when fires occur.

9.3.4 System of command in the internal fire service

The internal fire service should preferably be commanded by people who are in a position to have a broad view of the nature and extent of the risk, even in a fire emergency situation.

9.3.5 Operational command

An agreement should be reached in advance between the internal fire service and any external auxiliary units concerning operational command.

9.3.6 Communication

It is recommended that communication systems within each area should be adapted to one work effectively in conjunction with another in order to avoid delay in calling for assistance and to prevent misunderstandings when internal and external services are working together.

9.3.7 Special work

Fire prevention measures and, if necessary, control measures must be adopted before carrying out work which is outside the normal production schedule.
9.4 FIRE DETECTION AND ALARM

The way in which the alarm is raised depends on whether the fire is detected automatically or otherwise. The staff should be given thorough training on what to do if they detect a fire and how to operate the manual alarm systems (telephone, manual fire alarms). In the case of automatic fire alarm systems, care should be taken to ensure that the signal is transmitted and received reliably.

9.4.1 Automatic fire detection

If an automatic fire detection system is used, the method of detection (flame, smoke, temperature) should suit the location and nature of the possible types of fire.

9.4.2 System-generated false alarms

The alarm circuitry should be designed such that system-generated false alarms are minimized.

9.4.3 Environment-generated false alarms

Environment-generated false alarms resulting from incorrect methods of detection or incorrect alarm locations should be minimized.

9.4.4 Reception of alarm signal

The signal from automatic fire alarm systems, whether or not these are coupled to automatic extinguishing systems, should be transmitted to a control unit located in a safe and strategic place which is continuously manned.

9.4.5 Internal alarms

Alarms to order evacuation of the staff of a department should be chosen specifically for that department; they should be clearly audible at all times (in spite of background noise) and should be confined to the part of the plant in question. An external alarm may be given if necessary, to guide fire service personnel to the site of the fire.

9.4.6 Mobilization of industrial fire service

The signal mobilizing the fire service team(s) should be such that it does not cause panic or undue interest.

9.4.7 Calls for external assistance

It is preferable to have a direct telephone connection with the auxiliary services, in addition to the normal telephone line.

9.4.8 Design and maintenance of equipment

The construction, inspection, testing and maintenance of equipment should be carried out in accordance with the applicable regulations.

9.5 CLASSIFICATION OF FIRES ACCORDING TO EUROPEAN STANDARD EN 2 of 1973

The ability to extinguish a fire depends on one or more of the following actions of the extinguishing media:
- the interruption in the supply of fuel (cover);
- the interruption in the supply of oxygen (cover);
- cooling of the fuel to below the ignition temperature;
- negative catalysis (= inhibition of the combustion process);
- change in the ratio of the flammable mixture (fuel/oxygen dilution).

The extinguishing media depending on their extinguishing action are therefore suited specifically to extinguish flammable materials in certain categories.

9.5.1 Fire water

9.5.1.1 Source of fire water

Fire water may be drawn from:
- open water;
- waterworks companies;
- streams;
- tanks;
- storage basins (incl. cooling tower basins);
- combinations of the above.

In view of the fact that the supply of fire water must be guaranteed at all times, allowance must be made in selecting a source of fire-extinguishing water for the possibility of freezing, drying out, pollution, etc.

9.5.1.2 Volume of fire water

The volume of fire water must be commensurate with the fire risk; factors to be taken into account are fire load, rate of combustion, spread of the fire, cooling of equipment and tanks, etc. Depending on the type of system (e.g. as a part of the cooling water supply system), it must be possible to use the required amount of fire-extinguishing water without restricting the supply of cooling water to the plant and equipment connected to the system. Refer to 7.3.2 regarding the drainage of fire water.

9.5.1.3 Pressure

The supply pressure on the fire-extinguishing water must be adequate to meet the nature and extent of the fire risk (height of buildings or plants, safe distance for firefighting, etc.). It should be borne in mind that a certain pressure is necessary for the proper operation of permanent extinguishing systems.
9.5.1.4 Water mains for firefighting

The underground main for fire water must be kept full at all times and maintained at a slight over-pressure. Care must be taken to ensure that the supply of sufficient fire-extinguishing water is not interrupted as a result of power failure or a mechanical defect in the pump and main system.

9.5.1.5 Location of water pumps

The location of the water pumps must be selected such that the proper working of the pumps is not affected in the event of fire. Careful maintenance and thorough testing to ensure correct operation is essential.

9.5.1.6 Pipework and ancillary equipment for fire water

The following points must be borne in mind when designing pipework and ancillary equipment for fire water:
- the water should be supplied from two points so that the supply is not interrupted when parts of the system are shut off;
- the pipework should preferably run underground below the frost line;
- construction materials, protection and design are dependent on the local terrain conditions;
- surface pipework must be protected against mechanical damage, frost, fire and explosions;
- surface and underground hydrants must be situated such that a sufficient number of hydrants can be brought into use at all times;
- the spacing between hydrant should preferably not exceed 60 metres;
- underground hydrants should be marked so that they can be located easily in all weathers;
- suitable provisions must be made to facilitate action by external auxiliary services (for example, couplings);
- the location of pipework, hydrants, etc. must be indicated on an accurate drawing which is available on site.

9.5.1.7 Permanent installation

In addition to the systems described above, sprinkler systems may also be fitted. If the systems are fed by the fire extinguishing water supply, the volume of water mentioned in 9.5.1.2 and the pipe work mentioned in 9.5.1.6 should be calculated accordingly. The design and installation of the systems is generally governed by installation regulations.

9.5.2 Foam

In view of the fact that water is an important constituent of fire fighting foam, foam systems must fulfil the same conditions (frost protection, location of pipework etc.) as mentioned in 9.5.1.

9.5.2.1 Type

The type of foam (heavy, medium or light) must be chosen to suit the nature and extent of the risk.

9.5.2.2 Stability

The foam must not be affected by the medium to be extinguished or by any other extinguishing media which may be used simultaneously.

9.5.2.3 Efficiency

The means of applying an effective foam layer depends on the medium to be extinguished, and suitable provisions should be made accordingly. The efficiency of the foam system should preferably be determined by testing.

9.5.2.4 Storage life

Foaming agents may in some cases have a limited life, especially in the ready-to-use condition. Regular checking for foaming, sedimentation, contamination, etc., of the foaming agent is essential.

9.5.2.5 Viscosity

The foam system must be designed such that the viscosity of the foaming agent does not exceed the value indicated for this agent under any weather conditions.

9.5.2.6 Stock

The stock of foaming agent must be sufficient to cover at least twice the largest area for which foam extinguishing is required.

9.5.2.7 Capacity

In the case of heavy foam, the capacity of static foam systems should generally be such that a foam layer 25 cm thick can be applied to the whole of the area in question in 10 minutes.

9.5.2.8 Construction materials and design

At the design stage and when selecting construction materials, allowance must be made for the corrosive properties of water and foam.

9.5.2.9 Drainage

As regards the drainage of foam, it should be borne in mind that foam presents no risk to
the proper operation of waste water purification plants, oil traps, etc.

9.5.3 Powder

9.5.3.1 Type

The type of powder must be selected in accordance with the category of the medium to be extinguished.

A distinction is made between the following categories of fire:

Category A
Fires involving solid materials of primarily organic origin which generally become incandescent.

Category B
Fires involving liquid materials or materials which liquify.

Category C
Fires involving gases.

Category D
Fires involving metals.

9.5.3.2 Stoppages

Suitable precautions must be taken with static extinguishing systems to prevent plugging by excessively rapid build-up of gas pressure, condensation in the system, etc.

9.5.3.3 Capacity

The capacity of static and mobile firefighting units should be of the following order of magnitude, at least for fire categories B and C:

- in the case of surface fires, a capacity of at least \( \frac{4}{9} \) kg/m²/sec., based on sodium bicarbonate powder;
- in the case of space fires, a capacity of at least \( 0.6 \) kg/m³/sec., based on sodium bicarbonate powder.

9.5.3.4 Stock

The stock must be sufficient to maintain the supply rate stated in 9.5.3.3 for at least 10 seconds.

9.5.3.5 Output

The supply pipework must be designed to ensure that each spray nozzle gives the same output.

9.5.4 Gaseous extinguishing media

Gaseous extinguishing media may be divided into liquefied gases, cooled and compressed gases and gases under working pressure.

9.5.4.1 Applications

In general, gas extinguishing systems are primarily suitable for fighting fires in enclosed spaces, because gaseous extinguishing media work principally by reducing the oxygen content to below the peak value. The peak value depends on both the extinguishing gas and on the material to be extinguished. One of the factors affecting the choice of extinguishing gas is the possible occurrence of side-reactions which may, in their turn, produce dangerous situations, such as the generation of static electricity or the occurrence of undesired chemical reactions with the material to be extinguished.

9.5.4.2 Health hazard of gaseous extinguishing media

The use of gaseous extinguishing media brings with it the danger of asphyxiation. It is not only the gas itself which may be harmful to health - its decomposition products may have a similar effect.

9.5.4.3 Operating delay

In spaces in which people work and fire protection is provided by a gas extinguishing system, the functioning of the firefighting system must be preceded by an alarm. The interval between the alarm and the operation of the system must be adequate to allow the personnel to evacuate the area safely.

9.5.4.4 Gas requirement

The required rate gas depends largely on the plant or object which the system protects, and the stock of gas is determined on this basis.

9.5.4.5 Construction materials and design

The construction materials and design of the firefighting system must make allowance for any corrosive properties of the extinguishing medium. Low temperatures may also present problems.

9.5.4.6 Correct operation

It is essential to ensure that the extinguishing system operates correctly at all times. Important factors affecting this are: the location, the temperature and the pressure. Allowance should also be made for the possibility of generation of static electricity.

9.5.5. Other extinguishing media

In addition to the above mentioned extinguishing media, which are of a fairly general nature and which may be taken to include...
CHECK-LIST

steam, there are other specific extinguishing media whose effect depends on one or more of the properties described above (water, foam, powder, gas). Dangerous side-effects (for example static electricity, toxic vapours) or low efficiency of such extinguishing media will determine whether a specific extinguishing medium is necessary and which medium is most suitable. It should be pointed out that water is the only effective medium in cases where explosive combustion processes can take place.

10. GENERAL EMERGENCY PLANNING

10.1 INTRODUCTION

If, despite all the measures that have been taken, an emergency does arise, it must be possible to fall back on established emergency facilities and procedures, because in an actual emergency situation there is no time to develop a plan of action to deal with all the possible consequences. Emergency precautions must undergo continuous revision in line with changing circumstances and all possible eventualities must be provided for (see Section 3). Suitable precautions are:

- measures in case of an operational emergency situation
- measures in case of escape of liquids and gases
- measures in case of fire and explosion
- personal protective clothing and equipment
- training and maintenance
- communication systems
- briefing and employee information.

10.2 OPERATIONAL EMERGENCY SITUATIONS

If serious operational anomalies cannot be corrected by automatic or manual action, an emergency situation may arise that demands special countermeasures - if possible according to a pre-determined plan. An example is the situation in which a plant may find itself in the event - despite all precautions - of failure of the cooling system for the low-temperature atmospheric storage of liquefied gas.

10.3 ESCAPE OF LIQUIDS AND GASES

Measures must be taken to counteract the consequences of a liquid or gas escape. The plant must have contingency plans for such emergency situations. Examples:

- the escape of liquid to surface water
- the escape of flammable or explosive gas to atmosphere
- the escape of toxic gas.

What is the gas alarm drill?

Are all naked flames extinguished as part of the procedure?

Are all sources of ignition removed?

Is traffic diverted?

Is gas detection carried out etc.?

Is the alarm easily distinguished from the fire alarm?

Is there a readily visible wind sock to indicate the appropriate direction of retreat?

10.4 FIRE AND EXPLOSION

Despite numerous precautions the risk of fire and/or explosion cannot be excluded. Quick action is required if a fire or explosion is
not to develop into a calamity.

Examples:
- is it possible to isolate a burning process unit from neighbouring units?
- is it possible to rapidly cut off the supply of flammable liquids and depressurize the burning unit?

10.5 PERSONAL PROTECTION

In addition to all the regular personal safety precautions necessary under normal circumstances, care must be taken to ensure that:
- there is a plan to safeguard personnel in case of escape of toxic flammable gas (closing windows, extinguishing of naked flames, indication of safe areas and if necessary the appropriate routes to follow, etc.)
- non-company personnel are provided with the same safety facilities as regular staff and are also aware of the procedure to follow in case of emergency
- medical treatment facilities are appropriate to the risks associated with the plant (number, situation and capacity).

10.6 TRAINING

Any emergency precautions are useless unless proper training is given to the people likely to be involved (including external emergency services).

10.7 COMMUNICATION SYSTEMS

Essential to the effectiveness of any emergency measures are delegation of command and the proper functioning of the communication system.

Examples:
- is there an alarm and control centre from which operations can be directed in an emergency situation?
- and is there a back-up control centre in case of failure of the first?
- are all telephone numbers and procedures known relating to the local emergency exchange and external emergency services (fire brigade, police and medical services)? Is there a system whereby it is possible to obtain all the services by dialling only one number? Is there a separate telephone line?
- what back-up systems of communication are there if the telephone fails? Are personnel familiar with the use of these systems and do the systems function properly in conjunction with each other?

10.8 BRIEFING AND INFORMATION SERVICES

Expert and clear information should be given to publicity media.
Afsluitbare apparatuur

Gas in

E-1

PSV 1

Compressor

Driver

Gas out

Pos. verplaatsingspompen

Exhaust steam

Steam in

Turbine

Pump

Stoomturbines

Afsluitbare leidingen

Cold liquid

Hot liquid

Feed

Overhead vapor

Reflux

Accumulator

Product

Overdruk t.g.v.: uitval instrument
uitval koelwater
sluiten A

Destillatiekolom

Steam

Reboiler

FRC

CW
Het coderen van leidingen, enz. met nummers, kleuren of anderszins voor­komt vergissingen en draagt bij tot de veiligheid. (Zie b.v. BS 1710)

<table>
<thead>
<tr>
<th>Pipe contents</th>
<th>Basic colour (approximately 150 mm)</th>
<th>Colour code indication</th>
<th>Basic colour (approximately 150 mm)</th>
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<tr>
<td>Water</td>
<td>Green</td>
<td>Blue</td>
<td>Green</td>
</tr>
<tr>
<td>Drinking</td>
<td>Green</td>
<td>White</td>
<td>Green</td>
</tr>
<tr>
<td>Cooling (Primary)</td>
<td>Green</td>
<td>White</td>
<td>Green</td>
</tr>
<tr>
<td>Boiler feed</td>
<td>Green</td>
<td>White</td>
<td>Green</td>
</tr>
<tr>
<td>Condensate</td>
<td>Green</td>
<td>White</td>
<td>Green</td>
</tr>
<tr>
<td>Chilled</td>
<td>Green</td>
<td>Blue</td>
<td>Green</td>
</tr>
<tr>
<td>Central htg &lt; 100°C</td>
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<td>Blue</td>
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<tr>
<td>Central htg &gt; 100°C</td>
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<td>Cold, down service</td>
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<td>Green</td>
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<td>Hot water supply</td>
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<td>Blue</td>
<td>Green</td>
</tr>
<tr>
<td>Hydraulic power</td>
<td>Green</td>
<td>Salmon pink</td>
<td>Green</td>
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<tr>
<td>Sea, river, untreated</td>
<td>Green</td>
<td>Safety red</td>
<td>Green</td>
</tr>
<tr>
<td>Compressed air</td>
<td>Light blue</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vacuum</td>
<td>Light blue</td>
<td>White</td>
<td>Light blue</td>
</tr>
<tr>
<td>Steam</td>
<td>Silver grey</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drainage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrical conduits and ducts</td>
<td>Orange</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Town gas</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manufactured gas</td>
<td>Yellow ochre</td>
<td>Emerald green</td>
<td>Yellow ochre</td>
</tr>
<tr>
<td>Natural gas</td>
<td>Yellow ochre</td>
<td>Yellow</td>
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<td>Oils</td>
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<tr>
<td>Diesel fuel</td>
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<tr>
<td>Hydraulic power</td>
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<td>Salmon pink</td>
<td></td>
</tr>
<tr>
<td>Transformer</td>
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<td></td>
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</tr>
<tr>
<td>Acid and alkalis</td>
<td></td>
<td>Violet</td>
<td></td>
</tr>
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</table>
# APPENDIX 5.1

## TYPICAL SOURCES OF PLANT MAINTENANCE COST

<table>
<thead>
<tr>
<th>Source</th>
<th>Percentage</th>
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</thead>
<tbody>
<tr>
<td><strong>DAY-TO-DAY</strong></td>
<td>35 - 40 %</td>
</tr>
<tr>
<td>1/4 - breakdown</td>
<td></td>
</tr>
<tr>
<td>1/4 - operation</td>
<td></td>
</tr>
<tr>
<td>1/4 - design</td>
<td></td>
</tr>
<tr>
<td>1/4 - other</td>
<td></td>
</tr>
<tr>
<td><strong>PROGRAMMED</strong></td>
<td>20 - 25</td>
</tr>
<tr>
<td><strong>SHUTDOWN</strong></td>
<td>30 - 40</td>
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<tr>
<td><strong>STATUTORY</strong></td>
<td>~ 5</td>
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<tr>
<td><strong>PLANT CHANGE</strong></td>
<td>~ 5</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td>100 %</td>
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APPENDIX 6.0

COST DATA SHEET

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<tr>
<th>BY KMG</th>
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<tbody>
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<td>EXPONENT</td>
<td></td>
</tr>
<tr>
<td>TIME BASE</td>
<td>MID 1970</td>
</tr>
</tbody>
</table>

Use this data to establish relationships between process units cost and other cost centers in the capital investment. This is "order of magnitude" data for preliminary estimates.

SITE PREPARATION

COST OF LAND
ACCESS TO SITE
- Raw Material, Product, and Utility Pipelines
- Sewer Lines
- Access Road and Railroad Spur
- Right-of-Ways

SITE PREPARATION
- Site Grading, Drainage and Excavation
- Roads and Parking Areas
- Chemical, Storm, and Sanitary Sewers
- Fire Protection System
- Railroad Tracks
- Street Lighting
- Surface Treatment (Oiling, Graveling)
- Fencing

INDUSTRIAL BUILDINGS

OFFICE BUILDING
MAINTENANCE SHOPS
OPERATING MATERIALS WAREHOUSE
GUARD HOUSE
DISPENSARY
SAFETY DEPARTMENT BUILDING
CAFETERIA
GARAGE OR CARPORT
PLANT CONTROL LABORATORY
TECHNICAL SERVICE LABORATORY
UTILITIES CONTROL HOUSE
SHIPPING OFFICE
CHANGE HOUSE
MAINTENANCE MATERIALS WAREHOUSE

STORAGE FACILITIES

RAW MATERIALS STORAGE
IN-PROCESS MATERIALS STORAGE
PRODUCT STORAGE
PROCESS CHEMICALS STORAGE

Figure 6.5A Unit factors
Use this data to establish relationships between process units cost and other cost centers in the capital investment. This is "order of magnitude" data for preliminary estimates.

**UTILITY PLANTS**
- Electric power substations
- Water wells and clarification facilities
- Water storage
- Water treating facilities
- Plant air compressors
- Instrument air compressors and dryers
- Fuel blending and storage facilities
- Steam boilers
- Cooling water tower and pumping system
- Utility chemicals receiving and storage

**AUXILIARY FACILITIES**
- Blowdown systems and flare stack
- Incinerator
- Chemical sewage treating facilities
- Effluent water treating facilities
- Compressor oil recovery facilities
- Communications systems
- Emergency power generation
- Railroad scales
- Truck scales
- Landscaping
- Loading heads

**OFFSITE PIPING**
- Raw materials to process units
- Products from process units
- Materials between process units
- Raw water
- Potable water
- Treated water
- Condensate distribution
- Condensate collection
- Plant air
- Instrument air
- High pressure steam
- Medium pressure steam
- Low pressure steam
- Process chemicals
- Effluent stream collection
- Cooling water supply
- Cooling water return
- Fuel gas distribution
- Fuel oil distribution
- Fuel oil return collection
- By-product fuel collection

Figure 6.5B Unit factors
APPENDIX 6.I.

Cost calculations

Costs of an apparatus can be found in Webci[19] but not every apparatus used in the plant is given in this book therefore cost calculations for these apparatus are given below:

Costs of the storage tanks.

For cost calculations of storage tanks the following formula is used:

\[ C_{st} = C_{sto} \times F_m \times \left( I/336.2 \right) \]

In which: 
- \( C_{sto} = \exp \left( 7.483 + 0.6255 \ln V_{tank} \right) \)
- \( F_m = \) material vessel = 1 (carbon steel)
- \( V_{tank} = \) tank volume
- \( I = \) Chemical Engineering Plant Cost Index

\[ I = \frac{I_{equipment} + I_{tanks}}{2} = \frac{396.8 + 367.5}{2} = 382.2 \]

Calculations for each storage tank follow below:

-MEG tank:

\[ C_{sto} = \exp \left( 7.483 + 0.6255 \ln 37.5 \right) = 17,200 \]

\[ C_{st} = 17,200 \times 1 \times \left( 382.2/336.2 \right) = 19,500 \text{ US$} \]

So the MEG tank costs about 36,000 Dutch guilders.

-Crude MEG tank:

\[ C_{sto} = \exp \left( 7.483 + 0.6255 \ln 200 \right) = 48,880 \]

\[ C_{st} = 48,880 \times 1 \times \left( 382.2/336.2 \right) = 55,600 \text{ US$} \]

So the crude MEG tank costs about 102,300 Dutch guilders.

-MEG with KAC tank:

For this tank the above mentioned formulas are not valid because it's volume is too small.

For this tank a assumed price is 2,000 Dutch guilders.
- Dry PU storage:

\[ C_{sto} = \exp(7.483 + 0.6255 \ln 40) = 17.862 \]
\[ C_s = 17.862 \times 1 \times (382.2/336.2) = 20.300 \text{ US$} \]

So this tank costs about 37,160 Dutch guilders.

- Storage tank before the reactor:

\[ C_{sto} = \exp(7.483 + 0.6255 \ln 250) = 56,200 \]
\[ C_s = 56,200 \times 1 \times (382.2/336.2) = 63,890 \text{ US$} \]

So this tank costs about 117,600 Dutch guilders.

All together these 5 storage tanks cost about 295,000 Dutch guilders.

Costs of the mixer unit.

For the mixer unit as mentioned in chapter 1 the following equipment is needed:
- Silverson's in line high shear mixer L700
- Tank of 12.5 m$^3$ inclusive mixer
- About 5 m piping

The cost calculation of the equipment follows below:

- High shear mixer L700 costs: 45,000 Dutch guilders
- Tank of 12.5 m$^3$ inclusive mixer: 56,000 Dutch guilders
- 5 meter piping with a diameter of 100 mm: about 150 Dutch guilders.

So the total mixer unit will cost 101,000 Dutch guilders.

Costs of the heat exchanger.

For cost calculations of a heat exchanger the following formula is used:

\[ C_{he} = C_{heo} \times F_p \times F_t \times (I/336.2) \]

In which: \( C_{heo} = \exp(a + b \ln A) \)
- \( F_p = \) pressure factor = 1
- \( F_t = \) type of heat exchanger factor = 0.8
- \( I = \) Chemical Engineering Plant Cost Index = 367.5
- \( a = 7.085 \)
- \( b = 0.656 \)

In the table below the costs of all the heat exchangers are calculated:
<table>
<thead>
<tr>
<th>Heat exchanger nr. (see PFD)</th>
<th>Area [m²]</th>
<th>$C_{heo}$ [US$]</th>
<th>$C_{he}$ [US$]</th>
<th>Prize [Fl]</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td>385</td>
<td>59,278</td>
<td>53,910</td>
<td>99,194</td>
</tr>
<tr>
<td>H2</td>
<td>1</td>
<td>1,194</td>
<td>1,086</td>
<td>2,000</td>
</tr>
<tr>
<td>H3</td>
<td>37</td>
<td>12,756</td>
<td>11,600</td>
<td>21,346</td>
</tr>
<tr>
<td>H4</td>
<td>13</td>
<td>6,423</td>
<td>5,841</td>
<td>10,748</td>
</tr>
<tr>
<td>H5</td>
<td>0.3</td>
<td>542</td>
<td>493</td>
<td>900</td>
</tr>
<tr>
<td>H6</td>
<td></td>
<td></td>
<td></td>
<td>200,000</td>
</tr>
<tr>
<td>H7</td>
<td></td>
<td></td>
<td></td>
<td>200,000</td>
</tr>
<tr>
<td>H8</td>
<td>0.2</td>
<td>415</td>
<td>378</td>
<td>695</td>
</tr>
<tr>
<td>H9</td>
<td>33</td>
<td>11,834</td>
<td>10,762</td>
<td>19,800</td>
</tr>
<tr>
<td>H10</td>
<td>0.2</td>
<td>415</td>
<td>378</td>
<td>695</td>
</tr>
<tr>
<td>H11</td>
<td>0.3</td>
<td>542</td>
<td>493</td>
<td>900</td>
</tr>
<tr>
<td>H12</td>
<td>39</td>
<td>13,204</td>
<td>12,009</td>
<td>22,096</td>
</tr>
<tr>
<td>H13</td>
<td>4</td>
<td>2,964</td>
<td>2,696</td>
<td>4,960</td>
</tr>
<tr>
<td>H14</td>
<td>0.6</td>
<td>854</td>
<td>777</td>
<td>1,429</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>110,421</td>
<td>100,423</td>
<td>584,763</td>
<td></td>
</tr>
</tbody>
</table>

Costs of the flash vessels.

For cost calculations for a flash vessel the cost calculations of a pressure vessel is used.

For a pressure vessel the following formula is used:

$$C_{pv} = C_{pvo} \times F_m \times F_p \times (I/336.2)$$

In which: $C_{pvo} = (a + b \times L) \times d^{1.1}$

- $a = 1500$
- $b = 1100$
- $L =$ hight of vessel = 3.5 meter
- $D =$ diameter of vessel = 1.2 meter
- $F_m =$ material factor = 1 (carbon steel)
- $F_p =$ pressure factor = 1.1 (0.1 bar under pressure)
- $I =$ Chemical Engineering Plant Cost Index

$$I = \frac{I_{equipment} + I_{tanks}}{2} = \frac{396.8 + 367.5}{2} = 382.2$$
Filling in these formulas yields:

\[
C_{pvo} = (1500 + 1100 \times 3.5) \times 1.21^{1.1} = 6538
\]
\[
C_{pv} = 6538 \times 1 \times 1.1 \times (382.2/336.2) = 8175 \text{ US$}
\]

And:

\[
C_{pvo} = (1500 + 1100 \times 2.0) \times 0.61^{1.1} = 2100
\]
\[
C_{pv} = 2100 \times 1 \times 1.1 \times (382.2/336.2) = 2630 \text{ US$}
\]

So the flash vessels cost about 18,400 Dutch guilders.

Costs of the stripper.

For cost calculations of a stripper the following formula is used:

\[
C_{co} = C_{pv} + C_{int}
\]

In which: \( C_{pv} = C_{pvo} \times F_m \times F_p \times (I_{pv}/336.2) \)
\( C_{pvo} = (a + b \times H) \times D^{1.1} \)
\( C_{int} = \text{cost of column internals} \)

\( a = 1294 \)
\( b = 1141 \)
\( H = \text{height of column} \)
\( D = \text{diameter of column} \)
\( F_m = \text{material factor} = 1 \) (carbon steel)
\( F_p = \text{pressure factor} = 1 \) (1.0 bar)
\( I_{pv} = \text{Chemical Engineering Plant Cost Index} = 382.2 \)

Filling in these formulas for the Tray column yields:

\[
C_{pvo} = (1294 + 1141 \times 8.5) \times 0.221^{1.1} = 2080
\]
\[
C_{pv} = 2080 \times 1 \times 1 \times (382.2/336.2) = 2360 \text{ US$}
\]

For a Tray column the next formula for \( C_{int} \) is used:

\[
C_{int} = N_{tr} \times C_{tr} \times F_m \times F_{nt} \times F_{tt} \times (I_{int}/336.2)
\]

In which: \( C_{tr} = 58.7 + 88.4 \times D + 52.9 \times D^2 \)
\( N_{tr} = \text{number of trays} = 43 \)
\( F_m = \text{number of trays factor} = 1 \)
\( F_{nt} = \text{tray type factor} = 1 \)
\( I_{int} = \text{Chemical Engineering Plant Cost Index} = 355.7 \)

\[
C_{tr} = 58.7 + 88.4 \times 0.22 + 52.9 \times 0.22 = 81
\]
\[
C_{int} = 43 \times 81 \times 1 \times 1 \times 1 \times (355.7/336.2) = 3685 \text{ US$}
\]

And finally: \( C_{co} = 2360 + 3685 = 6000 \text{ US$} \)

So the Tray column costs about 11,000 Dutch guilders.
Costs of the packed distillation column.

For a distillation column the same formulas can be used as for a stripper. Same calculations as above lead to the prize of the distillation column. This prize is:

130,100 Dutch guilders.
<table>
<thead>
<tr>
<th>Apparatus</th>
<th>Costs [Hfl]</th>
<th>Obtained from</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Feed Section</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Storage Crude MEG</td>
<td>102,300</td>
<td>A</td>
</tr>
<tr>
<td>Storage MEG</td>
<td>36,000</td>
<td>A</td>
</tr>
<tr>
<td>Storage MEG + KAC</td>
<td>2,000</td>
<td>A</td>
</tr>
<tr>
<td>Cutter 1</td>
<td>150,000</td>
<td>O</td>
</tr>
<tr>
<td>Cutter 2</td>
<td>250,000</td>
<td>O</td>
</tr>
<tr>
<td>Storage dry Pu</td>
<td>37,160</td>
<td>A</td>
</tr>
<tr>
<td>Screw</td>
<td>13,000</td>
<td>W</td>
</tr>
<tr>
<td>Mixing vessel (incl. mixer)</td>
<td>56,000</td>
<td>W</td>
</tr>
<tr>
<td>In line mixer</td>
<td>45,000</td>
<td>O</td>
</tr>
<tr>
<td>Weight unit</td>
<td>19,000</td>
<td>O</td>
</tr>
<tr>
<td>Pre-reactor storage</td>
<td>117,600</td>
<td>A</td>
</tr>
<tr>
<td>Flash vessel</td>
<td>13,500</td>
<td>A</td>
</tr>
<tr>
<td>MEG stripper</td>
<td>11,000</td>
<td>A</td>
</tr>
<tr>
<td>Gas dryer</td>
<td>40,000</td>
<td>O</td>
</tr>
<tr>
<td><strong>Reaction section</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reactor 1</td>
<td>73,000</td>
<td>W</td>
</tr>
<tr>
<td>Reactor 2</td>
<td>78,000</td>
<td>W</td>
</tr>
<tr>
<td>Isolation vessel 1</td>
<td>12,650</td>
<td>W</td>
</tr>
<tr>
<td>Isolation vessel 2</td>
<td>8,350</td>
<td>W</td>
</tr>
<tr>
<td>Filter system (72-S-I)</td>
<td>9,500</td>
<td>O</td>
</tr>
<tr>
<td>Settler</td>
<td>7,000</td>
<td>W</td>
</tr>
<tr>
<td>Distillation column</td>
<td>130,100</td>
<td>A</td>
</tr>
<tr>
<td><strong>Work-up section</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rotating Dsc Extractor</td>
<td>57,000</td>
<td>O</td>
</tr>
<tr>
<td>2 Ion exchangers</td>
<td>3,200</td>
<td>O</td>
</tr>
<tr>
<td>Flash vessel</td>
<td>4,880</td>
<td>A</td>
</tr>
<tr>
<td><strong>Rest</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14 Heat exchangers</td>
<td>584,763</td>
<td>A</td>
</tr>
<tr>
<td>26 Pumps (13 spare)</td>
<td>52,400</td>
<td>W</td>
</tr>
<tr>
<td><strong>Total fixed investment</strong></td>
<td>1,913,400</td>
<td></td>
</tr>
</tbody>
</table>

Table 6.3
APPENDIX 6.11

Calculation of the amount of burned natural gas for heating the oil.
From chapter 4 is known the Duties;

\[
\begin{align*}
H4 : & \quad Q_1 = 349 \text{ KW} \\
H7 : & \quad Q_2 = 4625 \text{ KW} \\
\text{Qtot} = & \quad 4974 \text{ KW}
\end{align*}
\]

The amount of heat that has to transferred from the hot oil is Qtot. This transferred heat (Qtot) is put into the oil in a furnace where natural gas is burned. Assuming that the pipes from the furnace to the heat exchangers are perfectly isolated and there is no heat loss in the heat exchangers. The furnace has a certain efficiency \( \eta = 40\% \). So the supplied heat from burning is:

\[
Q_{\text{supp}} = \frac{\text{Qtot}}{\eta} = \frac{4974}{0.4} = 12,435 \text{ KW}
\]

From Montfoort[2] is taken the released heat by burning of natural gas. \( Q_{\text{bur}} = 31.65 \text{ MJ/m}^3 \). This means that for the required heat \( Q_{\text{supp}} \) the burned amount of natural gas is;

\[
q_{\text{gas}} = \frac{Q_{\text{supp}}}{Q_{\text{bur}}} = \frac{0.39}{31.65} \text{ m}^3/\text{s} = 1404 \text{ m}^3/\text{h}
\]
APPENDIX 6.III

In chapter 4 is given that 6 heat exchanger/condensers used water for cooling. These heat exchangers and the used amount water $Q$ is given in Table 6.III.1

<table>
<thead>
<tr>
<th>Heat exchanger</th>
<th>$Q_1$ (kg/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2</td>
<td>0.84</td>
</tr>
<tr>
<td>H5</td>
<td>0.12</td>
</tr>
<tr>
<td>H8</td>
<td>0.21</td>
</tr>
<tr>
<td>H10</td>
<td>0.06</td>
</tr>
<tr>
<td>H11</td>
<td>1.42</td>
</tr>
<tr>
<td>H14</td>
<td>0.42</td>
</tr>
<tr>
<td><strong>Total amount</strong></td>
<td><strong>3.07</strong></td>
</tr>
</tbody>
</table>

Table 6.III.1

In one hour is the used amount of cooling water $3.07 \times 3600 = 11.052 \text{ m}^3 / \text{h}$