1. INTRODUCTION

This Master's Thesis is a part of the co-operation between Lappeenranta University of Technology and Delft University of Technology, which consists of several theses considering the same theme from different viewpoints. This thesis is made in the in-house engineering company, Kemira Engineering Oy. Kemira Engineering Oy serves primarily the subsidiaries of the Kemira Group Companies: Kemira Agro Oy, Kemira Chemicals Oy and Kemira Pigments Oy.

The research focuses on knowledge transfer between two important groups in process design; designers and the plant's operating personnel. Knowledge transfer from operating personnel to designers is subject to special scruting. The subject has not been researched directly before and thus there is no documented information about the utilisation of operational knowledge in process design. Problems may first appear during first start-up and operation of the plant and operating personnel then express their dissatisfaction with the design.

At present, operational knowledge is utilised in the process design only to some extent. For example, designers make process safety analyses together with operating personnel. It is sometimes assumed that by utilising operational knowledge processes can be made more efficient, safer and environmentally sound and costs can be decreased. What is the real role of operational knowledge in design? At which stage can operational knowledge best be utilised? This work tries to find answers to these questions.

The objective of the work is to answer the questions:

1. How can operational knowledge management during a design process be improved?
2. How can operational knowledge improve the quality of process design?

First the subject is examined generally and then it is considered with the help of two case studies.

2. MAIN CONCEPTS

2.1 Process design

In this research, the process design considered was limited to an investment project, the focus of which is a chemical plant. The aim of process design is to plan a safe and functional process and plant. To reach this goal design is evaluated by quality criteria, which are introduced in the next section. Different laws and regulations constraint the process design. Process design works together with other disciplines, like automation and piping design.

The design process can, in general, be divided into stages:

Laboratory stage or literature research

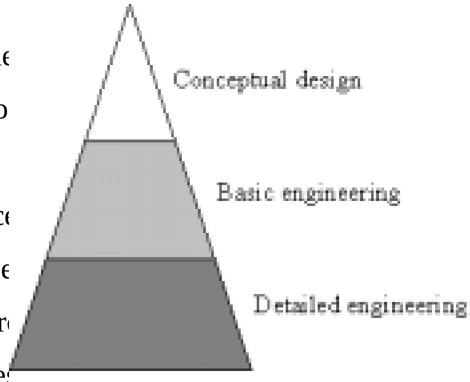
Conceptual design stage

Basic engineering

Detailed engineering

The laboratory stage is often done separately and is done by organisation other than the organisation carrying out the rest of the design process. The design proceeds from one stage to the next, but with feedback loops. These loops are the iterative returns to earlier stages, which are frequently necessary because of the quality of design /1/. Decreasing the number of iteration loops would shorten the design time. As the design goes forward the items become more detailed and all the design activities are based on the results of the earlier design decisions. The number of decisions made and the number of detailed facts increase as the design proceeds. This is presented in Figure 1.

Figure 1 The ocess increase as the design pro



The design proc the decisions made early in the design proce al design and commercial success of the pr hich provide the guidelines for the whole de sions can not be reversed in the later stages.

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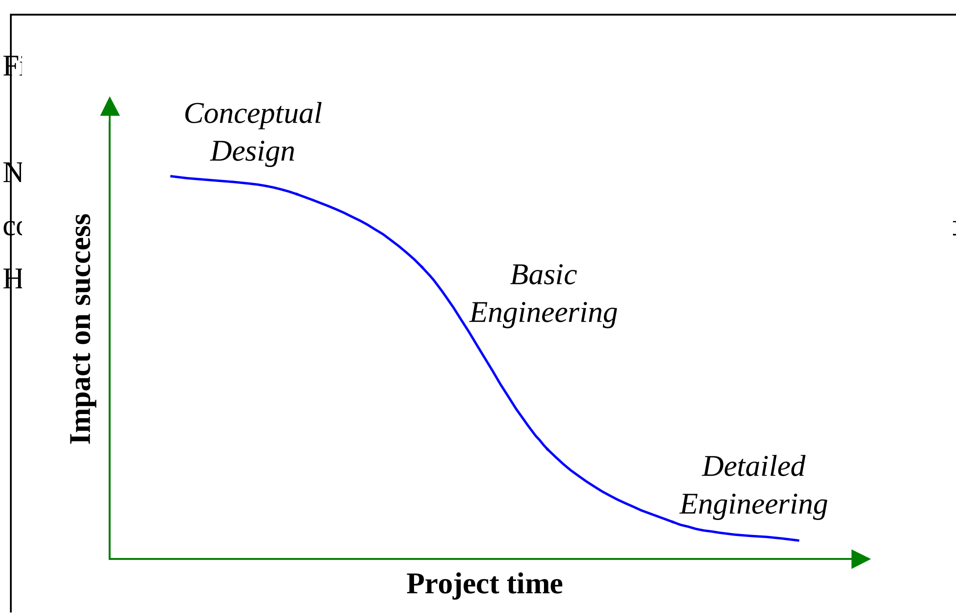

2.1.1 Conceptual design

The aim of the conceptual design stage is to gain a first impression of the profitability of an investment. The profitability of the investment is formed from an estimation of the investment cost, operating cost and production volume. A thorough analysis of the design problem and of the knowledge available is made in the conceptual design stage /2/. One source of information for this purpose is operational knowledge.

Important documents produced in the conceptual design stage are:

- Block diagram or preliminary flow sheet
- Preliminary process description
- Preliminary cost estimation
- Preliminary schedule
- Profitability calculation.

The block diagram consists of unit operations and raw materials. When choosing a unit operation for the process, operational knowledge is utilised of what has proved to be functional and economical. The safety and environmental impacts of these options are also considered. When designing a new process different unit operations and raw materials are tested in the laboratory or with pilot tests.

The estimation of the investment cost is made with 30-50 % accuracy in the conceptual design stage /2/. The accuracy improves as the design proceeds. The sources of information are equipment suppliers and different brochures and publications. Databases can be used if they are available. Estimation of the operating cost is difficult in the conceptual design stage, because the quantities of raw materials and utilities can only be obtained from the flow sheets, which will be made in the next stage. The management, which uses market research to establish the need, defines the production capacity.

2.1.2 Basic engineering

The aim of the basic engineering phase is to produce the documents needed for the detailed engineering phase and for the invitation for tenders. It is hard to draw an exact line between the basic and detailed engineering stages, so in investment projects the extent of every professional area has to be specified. The basic design begins with the process design, which gives information to the other disciplines. Changes to the basic engineering stage or incomplete information in the basic engineering stage is often the cause of time delays and budget overruns /2/.

Important documents produced in the basic engineering phase:

- Utility block diagram
- Material and energy balances
- Flow sheet
- Process description
- P& I diagram
- Safety analysis
- Technical duty specification of equipment
- Layout
- List of chemicals.

The block diagram of the utilities can be done when the equipment’s consumption of utilities has been defined. The operation values of the main process flows are shown in this diagram. List of chemicals is made on the basis of initial data and the flow sheet.

The utility block diagram is useful to clarify the requirements for operation and maintenance; especially when deciding space utilisation and control systems. The plan for space utilisation consists of delivery and storage chemicals, distribution of departments, safety aspects, space for different activities and the location of piping. The main equipment, main control loops and process streams are given in the flow sheet.

The equipment is chosen on the basis of the designers' experience and sometimes recommendations by the operating personnel.

All equipment, pipes, control loops and instruments are given in the P&I diagram. It is made in co-operation with the process design, piping and automation. The operating personnel make comments and suggestions when the preliminary P&I diagram has been made. The diagram is finalised according to the comments. Cost estimation in this stage is with 10-15 % accuracy /2/.

The technical duty specification of the equipment contains information about the materials used, the main dimensions, process circumstances, information of mass and special requirements. Operational knowledge can be applied when selecting material, in particular, the corrosion knowledge collected from real operating conditions is important. The right construction material is optimum for the investment and operating cost.

Operational knowledge is utilised in the process safety analyses. HAZOP is one well-known process safety analysis method. It is an abbreviation for 'Hazards and Operability'. It identifies hazards to personnel, company's property and the environment and problems that can prevent efficient operation. The team that carries out a HAZOP analysis varies but representatives from the design, process, operating and maintenance groups are all required /3/. HAZOP is made when the preliminary PI-diagrams have been completed /4/.

2.1.3 Detailed engineering

Process design is quite a small part in the detailed engineering phase, because most process design has been done in the basic engineering stage. The results of this design stage must be ready to permit the construction of the plant.

Plans made in basic design stage are specified and expanded in the detailed engineering. For example, 3D drawings can be used to analyse the accessibility of parts of the plant for operating personnel and maintenance personnel before it is even built /2/.

Making operating instructions is an important process design activity in this stage. The designers make instructions together with the operating personnel. The operating instructions consist of the actions in normal and in emergency situations.

Process designers take part in the plant personnel's training and in the start-up. In the training, knowledge is transferred from the designers to the operating personnel. The start-up is planned together with the design and management of operation.

2.1.4. Investment project

An investment project is always unique and it is allocated to a specific project organisation. This organisation is composed of professionals from different disciplines and is dismantled when the project is completed. A typical organisation chart is shown in Figure 3. Reliable and fast knowledge transfer between process design, other disciplines and operating personnel is one of the key elements for the project to be a success.

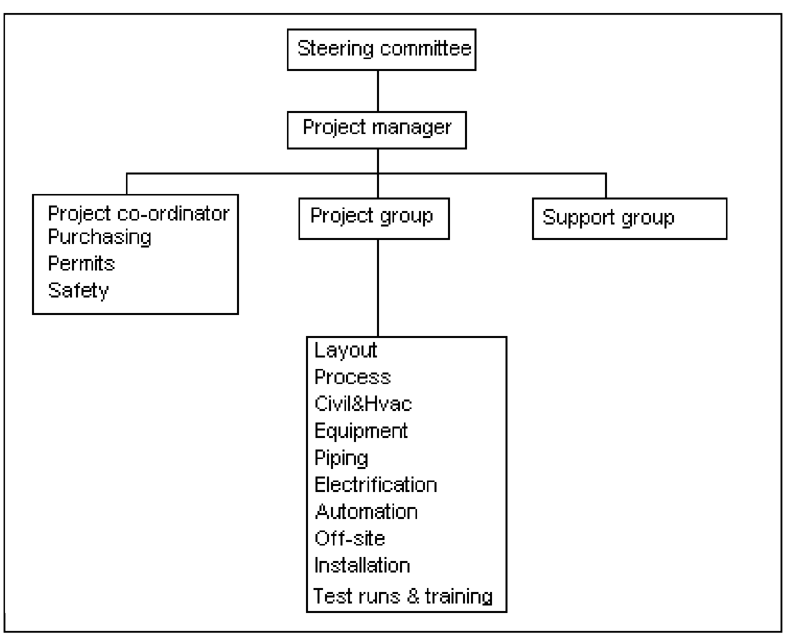

Figure 3 Typical project organisation

The project organisation comprise a steering group including the project manager, and a project group including the chief engineer, representatives of various disciplines, operating personnel and the site manager. The project group co-ordinates and takes care of the general assignments necessary to achieve the goal of the project. There are one or more representatives from every professional area in the project group. The project group meets regularly and the support group assists the project group during design.

The number and frequency of project meetings and people participating in these meetings vary and this has a great effect on how knowledge transfers. Co-operation between the professional areas also affects the results. Members of the group assist the project group during the project. Their main duty is to comment on the plans and to give the operational requirements, for example safety and operability considerations. The operating personnel is part of the group.

The object of a project may be a totally new plant, modernisation/retrofitting or the expansion of an existing plant. Examples of a process retrofit are projects to increase production capacity, utilise new process technologies or reduce operating costs /5/. Investment can be also compulsory because of changes in environmental protection legislation. Key project objectives include plant capacity, product quality (for example product specifications), schedule and cost. Sometimes project objectives can be stated with some practical guidelines. Project is, for example, schedule-driven /6/.

2.2 Quality criteria of process design

The quality of the process design can be evaluated in many ways. Here the quality is evaluated with seven criteria, which are shown in Figure 4. The quality criteria could be categorised in more detail or with different criteria, but this research is focused to the seven given in the figure.

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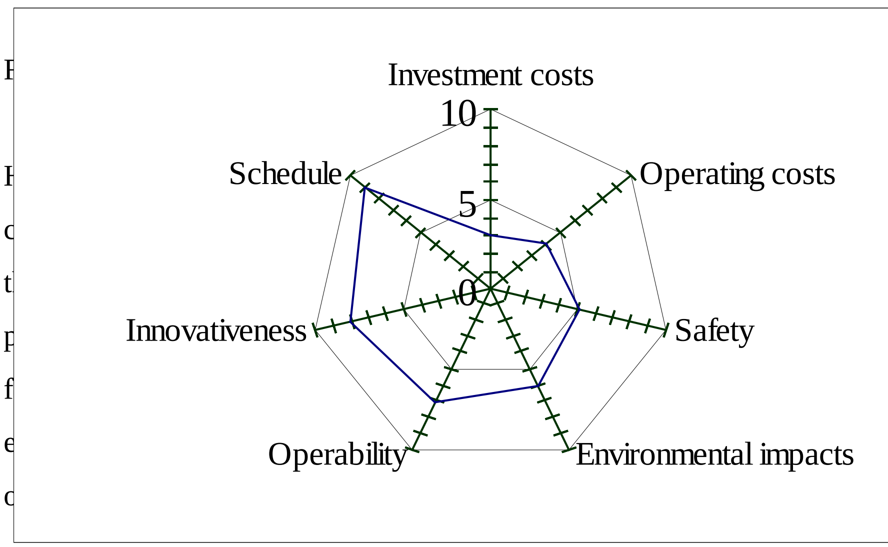


Significant is also when the evaluations are made; after the design or during the design? For example, it is too late to start to evaluate safety, when the plant is already functional. There is also the question of from which perspective the criteria are to be considered. There is difference in emphasis between designers and operating personnel. Furthermore, quality criteria may be interpreted differently. The object is that everyone in the project would have the same goal.

Figure 4 illustrates the nature of the quality criteria. The blue string indicates the value of the criterion on the green scale. If one of the quality criteria is improved, some other criterion can be worsened. For example, if safety is increased, investment- and operating costs will increase. In the figure the values in the scale are random. The criteria must be prioritised for the design to be optimised.

All the quality criteria are introduced in the different design stages. It is stated that each quality criteria should be considered earlier /7/. On the other hand it can be hard to carry out in practise /2/. Next the quality criteria are discussed more precisely. In the beginning of each section there is a definition of criterion considered.

2.2.1 Investment cost

Investment cost is the cost of the plant ready for start-up /8/. Sometimes start-up is included.

The quality of investment cost can be measured by comparing the final investment cost to the cost given in the investment proposal. Quality rises on the scale if it has been possible to reduce costs during design. The realised cost depends also on the evaluated cost. If the cost estimation is clearly too low, it is impossible to follow.

Machines and equipment are normally the biggest items. Other items are piping, automation, electrification etc. The investment cost is connected to the operating cost. Usually the operating cost will grow when the investment cost is decreased.

Capital bound in the investment cost is determined mostly during process design. In procurement and installation there are only limited possibilities to impact on the investment cost. The average cost of rework on industrial projects exceeds 12% of the total installed cost. Design deviations are responsible for 80% of this rework /6/. Therefore the influence of design solutions on the investment cost is inconsiderable /9/.

2.2.2 Operating cost

Operating cost born in the operation of the plant.

The quality of operating cost can be measured by comparing the realised operating cost to the cost given in the investment proposal. Qualified process design aims to minimise operating costs taking into consideration also the other targets.

The operating cost can be divided into two groups: the fixed operating cost and the variable operating cost. The division is dependent on the company. Fixed costs do not vary with production, for example, laboratory costs, insurance and licence fees. Variable costs are dependent on the amount of product produced, for example raw materials, utilities and maintenance. The division into fixed and variable costs is somewhat arbitrary.

Raw materials are usually the biggest part of variable costs, but utilities also take a big part. Utilities include power, steam, compressed air, cooling and process water, and effluent treatment; unless they are costed separately /8/.

Consumption of raw materials and utilities are defined in the basic engineering stage, but an approximation is made in the conceptual design stage. Maintenance is usually considered in the later stages of the design process /2/. If the schedule slips, the prices and availability of raw materials can change and the operating costs change. Demand for product can also change.

2.2.3 Safety

Safety is zero accident operation.

The quality of safety worsens when the first accident happens. Safety can be considered as good business; good management practices are needed to ensure safe operation that will ensure efficient operation /8/. Safe operation decreases also operating costs. However, you can not measure everything in monetary terms.

Safety is considered already in the conceptual design stage but the proper safety analyses are made in the basic engineering stage. Obviously, it is preferable to take the safety aspects into account as early as possible in the design. Things sometimes start to go wrong during the conceptual design stage. Designers do not know enough about safety-related aspects even though they are highly motivated /10/. Safe design solutions are more important than protection systems, which are added afterwards /4/. Furthermore, safety aspects have to be considered both in construction and during operation.

Risks to the employees are mechanical, physical, chemical and biological /4/. A big part of the risks in chemical plants consist of fire- and explosion accidents. Ergonomics is a part of safety.

2.2.4 Environmental impacts

Environmental impacts are the overall effect of the process on the environment.

Environmental impacts are measured as follows: releases during operation are compared to the limits which the authorities or the project has established. In Kemira, a statement of the environmental impacts of the project should describe and quantify the following aspects:

- Most important releases into air and water
- Generation of waste and hazardous waste
- Comparison of these mass flows with the existing or anticipated norms, limit
  conditions in environmental permits or national legislation
- Estimate of environmental capital expenditure and annual environmental operating cost

- Use and release of carcinogenic or otherwise very toxic or eco-toxic compounds
- Brief description of anticipated environmental impact of these releases (both normal and accidental) in the vicinity of the plant
- Brief description of the expected local public or extremist reactions to the project if necessary
- Brief description of existing soil and ground water contamination on the site, if the site has not previously been owned or operated by Kemira.

The environmental impacts are dependent on the technology used. In the future, environmental impacts can be measured in BAT (Best Available Techniques). BAT is defined in the European Union IPPC-directive (integrated pollution prevention and control).

Environmental impacts are talked about in the conceptual design stage but the emissions to the air and water are specified in the material balances calculated in the basic engineering stage. Sometimes emission measurements are good indicators of process operability. When the process is friendly to the environment, it is probably safe. Noise also should be included in the environmental effects.

2.2.5 Operability

Operability means how easily the process can be operated.

Operability is a very wide concept. It depends on many details in the process, like the equipment, control system, layout etc. Usually, operability is difficult to measure in numbers. Measurement data gives information about operating conditions in numbers, for example how temperature changes according to time. The best way to clarify the operability is to interview operators and other operating personnel personally. Are they satisfied with the operation of the process? Does the equipment function faultlessly and is the control system usable? Are there bottlenecks in the process? Bottlenecks restrict production. Flexibility, controllability and reliability can be counted as parts of the operability.

2.2.5.1 Flexibility

Flexibility is the ability of a design to readily adjust to meet alternative, desirable operating conditions /11/.

Future needs have to be taken account already during the design process, for example, requirements for expandability. Single process values and the production capacity belong to flexibility. There has to be the possibility to increase the capacity and to change raw materials. Sampling and cleaning possibilities are flexibility. The number of cleaning hatches in the equipment and their location affect cleaning. Different states of the process, like start-up, downtime and shutdown have to be controlled fluently and safely.

2.2.5.2 Controllability

Controllability means the ability of a process to reject disturbance and to maintain the process at the desired operating point /12/.

The process has to be kept in the desired state. One must be able to change the process values when necessary.

Controllability is included in safe plant operation to keep the process variables within known safe operating limits, to detect dangerous situations as they develop and to provide alarms, automatic shut-down systems and interlocks to prevent dangerous operating procedures /8/. Controllability is also included in the production rate to achieve the designed product output and quality to maintain the product composition within the specified quality standards. Nowadays, product quality is more than the right composition. Controllability affects the costs by permitting operation at the lowest production cost, commensurate with the other objectives.

2.2.5.3 Reliability

Reliability means uninterrupted flow of production and minimised maintenance cost. /13/

Failure-free production in the process is vital. Operating personnel has practical experience, for example, if certain valves leak. Technical faults cause discontinuation in production and increase operating costs in the form of maintenance costs and lost or delayed production.

2.2.6 Innovativeness

Innovativeness means generation and application of new ideas in design.

Innovativeness can be measured by the number of technical and economical improvements. The designer has to decide whether to create new technology or to use proven technology. The technology may be improved by new approaches and novel solutions. On the other hand, when using proven technology, the risks are minimised /7/. As the design process proceeds the innovativeness falls because big changes can not be made in later stages.

Several methods have been developed to improve designers’ or design teams’ ability to generate new technological solutions. Brainstorming is the most widely known creative method. This is a method for generating a large number of ideas, most of which will subsequently be discarded, but with perhaps a few novel ideas being identified as worth following up. It is normally conducted as a small group of people. The group of people should be diverse. /1/ It should include a wide range of expertise; maybe operating personnel too to bring up operational knowledge in the design.

The use of analogical thinking has been formalised in a creative design method known as a ‘synectics’. Like brainstorming, synectics is a group activity in which criticism is ruled out, and the group members attempt to build, combine and develop ideas towards a creative solution to the set problem. Synectics is different from brainstorming in that the group tries to work collectively towards a particular solution, rather than generating a large number of ideas /1/. There are many other methods to improve idea generation.

Innovativeness does not always mean a big revolutionary invention. Small changes can remarkably improve the final result of design. After all, few ideas in engineering ever prove to be fruitful; the same pattern holds for any type of creative activity /5/.

2.2.7 Schedule

The schedule is a plan of how much time is used for different tasks in the design process.

The schedule is measured against the plan. If production begins according to the preliminary plan, the design has been a success. Important is also to keep the schedule of different professional areas during design, because they are tightly connected to each other. The preliminary plan is made in the conceptual design stage.

The schedule is connected to the cost. Long delays cause extra cost: The bigger the investment, the more expensive the delays become. Many factors can cause schedule slippage. Information is not available or it is received too late. The schedule might also be too tight and therefore impossible to keep.

The time that is needed for design activities related to information processing, such as communication, negotiations, data retrieval and transfer, can comprise as much as 85%

of the total design time. The efficiency of the design process may be substantially improved by reducing the time that design engineers need for these activities /2/. On the other hand, project meetings are the most important way of communicating.

2.3 Classification of operational knowledge

Knowledge is very multiform concept. According to one classification, it can be considered to be composed of data and information. Data is codes, marks and signals. Information is when these codes, marks and signals are put in order and meaning or interpretation is added /14/. Knowledge is formed when new information is combined with old information. Figure 5 illustrates the composition of knowledge.

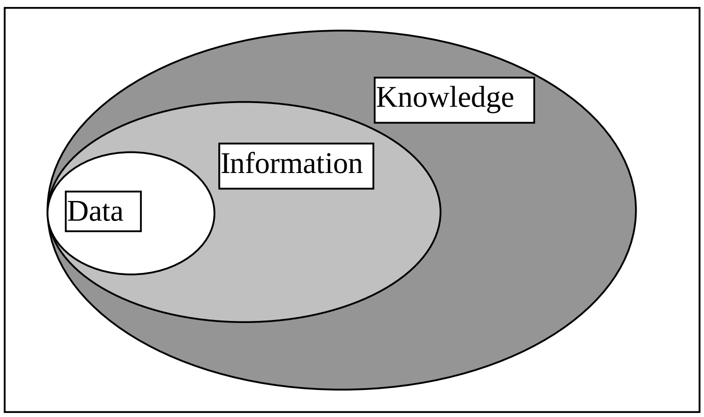
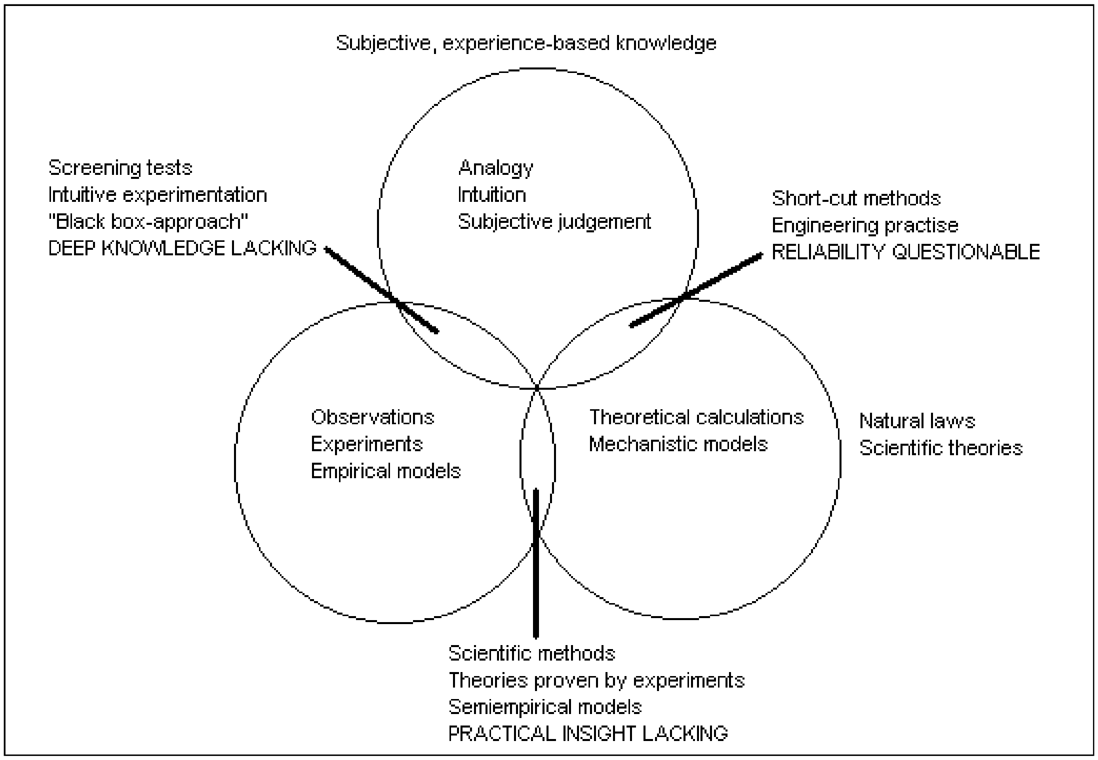


Figure 5 Composition of knowledge

Knowledge can be classified also in the other ways. One classification is according to the origin of the knowledge. Three sources of information have been introduced in Figure 6. The source of empirical knowledge is practical experience. Observations are made when running the process. Theoretical knowledge is based on natural laws and scientific theories. The third form of knowledge is subjective, experience-based knowledge. Knowledge is shallow or deep depending on its origin.



- How knowledge is acquired and where it can be acquired?
- Who acquires knowledge?
- When the best benefit is got from the knowledge – which means when is the right moment?

From the companies' point of view, the quantity of knowledge, its correctness and quick dissemination are important. /14/

Common problems in knowledge management /14/:

- Knowledge is believed to be unchanged. However it comes from people and it changes and develops.
- Knowledge is believed to be outside people although it always comes from people.
- Storing of knowledge is emphasised instead of transferring knowledge.
- Tacit knowledge is not noticed enough. Tacit knowledge is needed to collect, create, compare, combine and share explicit knowledge.

- Technology replaces contacts between people. Direct interaction between people is invaluable when exchanging knowledge and creating new knowledge.

Usually, knowledge is documented somehow. Without documentation knowledge is difficult to utilise. Is it then necessary to document all the knowledge? There is the risk that the documentation becomes too time consuming /17/.

In this research operational knowledge is defined briefly as:

→ *All knowledge obtained from operating industrial plants.*

Operational knowledge contains process measurement like pressure and temperature, operating personnel’s theoretical information, for example, obtained from training, operating personnel’s practical experience (empirical) knowledge, which comes through years of experience and common sense. All these, both individually and combined are operational knowledge.

Operational knowledge is mostly empirical knowledge. An operating person gets measurement data and makes conclusion on the basis of theory and practice. Visible observations of process circumstances belong to this practical knowledge. For example, an operating person can inform a designer if it is difficult to control temperature accurately in a column. Or if a manually operated valve is difficult to use because of its location.

Knowledge gained from experience of one process should be utilised in other processes if possible. Knowledge is also opinions, which are believed to be true. Books and publications, which contain general operational knowledge (for example the recommendation of pump manufacturer) are not included as operational knowledge.

Operators, process persons, shift supervisors and maintenance personnel are operating personnel, but also operating engineers and managers of operating personnel are counted the operation side. If they transfer to design, they bring operational knowledge with them. An equipment supplier can have practical operational knowledge from the use of their equipment in other plants. So it is difficult to say which knowledge comes from operating personnel and which knowledge comes from somewhere else. A more useful term might be organisational knowledge. /17/.

Operational knowledge is multi-level, because the operating personnel is composed of different kinds of people. Knowledge can be deep or shallow depending on the people.

Consequently there is a huge amount of knowledge obtained from plants. This knowledge can be categorised as knowledge that is not profitable for anyone and knowledge that can be utilised in the company. It is important to filter the valueless knowledge from valuable knowledge. Valuable knowledge has statements of reasons-answer to the question why.
Utilising operational knowledge in design is a matter of relationships and the nature of the people involved. Some knowledge is never available, because a person is not interested or does not dare or does not want to pass on the knowledge to be utilised in the design. On the other hand, some persons are very vocal with their opinions. When evaluating operational knowledge, designers have to be critical. Fluent relationships between operating personnel and designers facilitate the use of operational knowledge in design.

Operational knowledge is used in different quantities in every design stage. The important question needs to be asked: in which design stages should different kinds of operational knowledge be utilised and why? There are different answers to this question. Operational knowledge affects the quality criteria differently. The effect is greater on some criteria than others.

Operating personnel may have opposing opinions about an issue. The knowledge is then contradictory and it is difficult to utilise. Utilisation of operational knowledge varies according to design project. When designing a new plant which has (approximately) similar processes as used earlier, operational knowledge can more easily be used in design phase. But if the plant being designed is totally different from earlier ones, there is less operational knowledge or knowledge is more difficult to obtain.

Operational knowledge management is dependent on the relationship of the engineering office and the client. If the client is a group company, feedback from operating personnel can be obtained more easily. If the client is an outsider, things are not discussed so openly. Especially when developing new process, there is a risk that confidential knowledge is transferred to outsiders.

Why is it then useful to manage operational knowledge? Very few design errors result from technical incompetence. Rather, most result from poor communication /7/. By managing operational knowledge the quality of process design and operation of plants are supposed to improve.

3. UTILISATION OF OPERATIONAL KNOWLEDGE

3.1 Procedure

In the next section utilisation of operational knowledge is studied generally and in the case projects. The study was made using the Delphi method /18/. As applied here, the Delphi method consists of the following stages:

1. Interviewing personally external experts from industry.
2. Formulation of statements on the basis of these interviews (and literature).
3. Evaluation of statements in Kemira (designers and operating personnel): True/false and arguments.
1. Detailing of the statements for the case projects.
2. Evaluation of the statements by project personnel: True/false and arguments.

3. Conclusions.
4. Evaluation of operational knowledge management practise in Kemira and recommendations.

Assumptions and estimates are summarised from the interviews. On the basis of these assumptions and estimates, statements are formulated. The experts were from different disciplines outside Kemira. Persons from Neste Engineering, Valmet Corporation and Jaakko Pöyry Process Contracting were interviewed for this purpose. The interviewees were asked when operational knowledge should be utilised and how it affects the quality of process design. Then the statements were sent by email to 14 process designers and 8 persons from operations in Kemira and they evaluated the statements. The persons from Kemira operations were operating managers, shift supervisors etc. from Kemira's plants in Finland and abroad. The process designers commented on the results in a process department meeting and brought new ideas and justifications to the statements. This iteration loop was not used for the case studies because of the complicated arrangements needed.

3.2 Statements

The statements consisted of the seven quality criteria of process design discussed earlier. There were also statements about assumed problems in knowledge transfer between designers and operating personnel and improvement proposals.

Respondents were encouraged to debate the statements, especially when they disagreed with them in whole or part. The answers were handled without names. Inaccuracies and misunderstandings caused by the subjective background should be taken account when interpreting the answers of statements. People can overestimate their own knowledge and underestimate other's knowledge or vice versa.

3.3 Evaluation of statements

The statements are evaluated according to the quality criteria. The object to be designed was not mentioned in the statements. Operating personnel probably considered existing processes and designers both new and existing process when evaluating the statements.

The statements are given in the appendices. In horizontal row there is a grading scale and in vertical columns there is the number of statement. The mean value and the difference between the mean values for the designers and operating personnel have been calculated for every statement. When evaluating the statements, they have been divided into three groups: opinions from 1 to 2, opinions 3 and opinions from 4 to 5. Those who have answered 1 or 2 disagree and those who have answered from 4 to 5 agree with the statement. Those who answered 3 either have no opinion on the issue or do not want to express an opinion. One reason for answering 3 might be that the statement is not properly defined. Statements, which give divergent results are particularly interesting.

3.4 Analysis of the comments

3.4.1 Operational knowledge in different design stages

The statements, the results and comments are shown in the appendices 1-4.

The designers believed that operational knowledge is used most in basic engineering, for example, in the review of P&I diagram and layout. ‘The best time for utilising operational knowledge would be after the investment plan’. The impact on the final design decreases as the design proceeds. On the other hand, the number of decisions to be made is highest in the detailed engineering stage. One designer commented that ‘in the detailed engineering stage, process design is small part’. ‘There shouldn’t be any big changes in the detailed engineering’, meaning that the investment project would succeed better if there is no changes in detailed engineering. ‘Design should be emphasised also in the conceptual design stage' –timesaving in the beginning will rebound on later, was another comment. As a conclusion it can be said that, the greatest benefit from the utilisation of operational knowledge is achieved in the basic and the detailed engineering stages.

It seems that if possible a representative with operational knowledge should be involved already when the investment proposal is being prepared. Then the operational viewpoint would be seen right from the beginning.

Conclusions:

- **The number of decisions is highest in the detailed engineering phase and operational knowledge can best be applied then.**
- **Operational knowledge should be available at the latest in the beginning of the basic engineering stage.**

3.4.2 Costs

The statements, the results and comments are shown in the appendices 1-4.

One designer believed operating personnel has knowledge of cost regarding their own position. This is not very deep knowledge of cost. Some designers believed that operating personnel wants the most modern equipment, which is usually the most expensive. Knowledge of investment cost is not easily available to the operating personnel. Investment cost is not discussed as much as operating cost. Designers have to think about the total cost. Using operational knowledge makes process the more practical and easily controllable, as one operating person stated. Simplification of the process means, for example elimination of unnecessary machines or control loops, which decreases cost. 'Material selection in 99% of cases is based on experience.' Job rotation is one way of reducing costs, but it is difficult to arrange in practice.

Operating costs can be decreased by utilisation of operational knowledge, because operating personnel observe the process run. Costs can also increase when operational knowledge is utilised, because the operating personnel do not necessarily consider low costs a priority. Probably, operating persons do not have very deep knowledge of total costs.

Conclusions:

- **Operating and investment costs can be decreased in old plants by utilisation of operational knowledge.**
- **Investment costs can also increase if knowledge management is not organised well.**

3.4.3 Safety

The statements, the results and comments are shown in the appendices 1-4.

The subject of safety generated differing comments from the operating personnel and designers. One reason for the gap between the operating personnel and designers might be their different viewpoints. The operating personnel pays more attention to working safety than the designers, who think more about process safety. The designers considered operability a more important area in which to utilise operational knowledge than safety. One designer commented that operational knowledge of safety is too oversimplified. Safety is considered to be important in the plant and that is why operating personnel wants to impact on it. Probably, designers think more about cost and schedule. On the other hand, designers have responsibility for safety. 'Designer should know the safety rules and operating personnel just checks the plan and give ideas.' Safety is based more on theoretical knowledge, because there is less practical experience of lack of safety, at least severe accidents, like run-away reactions. Operating persons are supposed to know about the safety of existing plants, but in new plants or processes, the designer determines procedures. The operating personnel is believed to have the most knowledge of safety in start-ups and shutdowns.

Operating personnel wants to affect the safety of plants and processes, and designers have to be aware this. Operational knowledge about safety is more knowledge about working safety and ergonomics than process safety.

Conclusions:

- **Operating personnel and designers have different viewpoints regarding safety, operating personnel thinks about working safety whereas designers think about process safety.**
- **Operational knowledge has to be taken into consideration more when designing aspects of the plan involving working safety and ergonomics.**

3.4.4 Environmental impacts

The statements, the results and comments are shown in the appendices 1-4.
The designers disagreed with the operating personnel about operational knowledge of environmental impacts. The designers are responsible that the emissions do not exceed existing norms. The operating personnel has more detailed knowledge of emissions and effluents, which are visible and can be easily detected like leaks in pipelines. They might also have knowledge about the reuse of washing liquids, cleaning etc. The environmental impacts of the process releases are very specific knowledge. When considering these environmental impacts, knowledge is in designers or more probably some environmental specialist. The operating personnel have practical knowledge of single emissions from the process and they have to be listened to. Presumably, the operating personnel has noteworthy knowledge of emissions, which may not have been noticed during design.

Conclusions:

- **Operating personnel has knowledge of single ‘visible to the eye’ emissions of the process.**
- **Operating personnel does not have knowledge of the environmental impacts of the process.**

3.4.5 Operability

The statements, the results and comments are shown in the appendices 1-4.

Detailed design of control loops is based mostly on theoretical knowledge. Practical experience should be available in the design of appearance of the control system, which affects usability. Operators are in contact with the control system every day. ‘In some cases operating personnel’s technical understanding of the process may be limited, resulting in wrong conclusions’, believed one designer. Operating personnel believed they notice bottlenecks in the process during design, however designers did not believe this to be true. Maybe the designers had had the experience that operational knowledge is not complete. Or the designers and operating personnel understood the bottlenecks in the process differently. One designer believed that operating personnel will notice some of the bottlenecks in the process during design if the designer describes the plan carefully. One designer commented that all problems in the process run will not become evident until the plant starts operating, but good design can eliminate lots of anticipated problems. It seems that the operating personnel have an essential part to play in the operability of the process.

Conclusion:

- **Operational knowledge improves the operability of the process, for example controllability and flexibility.**

3.4.6 Innovativeness

The statements, the results and comments are shown in the appendices 1-4.

The innovativeness can be effected by operational knowledge, because problems usually surface when the process is run. Innovativeness is believed to be important in design, but it is not as easy a subject to talk about as cost. One argument goes, ’An exhilarating and active group of operating persons is the motor of project’. However, one designer noted that the project has to be under control despite being innovative.

Some technical problems can be resolved by utilisation of operational knowledge and sometimes the economics of the process becomes better. The designers have to listen to suggestions from the operating personnel early enough otherwise fulfilled changes cause extra cost. In the detailed engineering stage it is too late to perform major changes.

Conclusion:

- **Operational knowledge affects to innovativeness of the design and therefore improves the technology and economics of the process.**

3.4.7 Schedule

The statements, the results and comments are shown in the appendices 1-4.

The design period can be shortened by the utilisation of operational knowledge. ‘The wheel does not have to be reinvented’. Utilising operational knowledge can also lengthen the schedule, if the operating personnel make lot of suggestions and they all have to be followed up. One of respondents stated that practical implementation of ideas from operating persons takes time. The designer must take care that the project is kept on schedule. One designer believed that more streamlining during the organisation period could shorten the design time.

Conclusions:

- **Utilisation of operational knowledge shortens the design schedule if managed well.**
- **Operational knowledge can also lengthen the design schedule if the knowledge management is not controlled.**

3.4.8 Problems in the utilisation of operational knowledge

The statements, the results and comments are shown in the appendices 1-4.

Long distances, different objectives and time limitations were considered to be problems in utilisation of operational knowledge. Travelling between the plant and the design office takes time. A person from operation noted that the drawback of distance is getting smaller with today's equipment of knowledge transfer. All knowledge does not transfer best electronically. Designers should visit on site during the design. One designer concludes that distance is just the matter of organisation. It requires only a right attitude. Some see the differences between cultures as a bigger problem than the physical distance.
The objectives of the designers and operating personnel are not exactly the same: cost, schedule and ease of operation do regularly collide during design, expressed one designer. The operating personnel want a comfortable space for working when considering these differing objectives. One designer noted that plans are made for operation not for designers. Nevertheless, all the wishes of the operating personnel need not necessarily be met to ensure process operability. A necessity for success of the project is that everyone has the same objective. The operating personnel and designers should discuss design solutions and opinions should be given with the same objective in mind.

The designers might have to attend to many projects at the same time, so there are time limitations. The operating personnel are also busy and therefore it is difficult to arrange shared time. Time limitations are also a matter of organisation. One designer did not believe that operational knowledge is superficial –‘operating persons are familiar with the chemistry of the process’. Another said that it depends on the plant, they may not understand the fundamentals of the process. The designer has to think about the physical facts of the observed phenomena, noted one designer. Probably, operational knowledge is not very deep, but all design solutions are not based on deep theoretical knowledge. Operational knowledge should be used when deciding practical arrangements in the design.

Conclusions:

- **Long distance and time limitations are not problems, if people have the right attitude.**
- **Different cultures might cause problems.**
- **In discussions all participants should have the same objective.**
- **Operational knowledge is useful to solve practical problems.**

3.4.9 Methods to improve the utilisation of operational knowledge

The statements, the results and comments are shown in the appendices 1-4.

Some kind of a systematic follow-up would prevent the same mistakes being made again. Then yet why this is not organised? Implementation of project follow-up system takes money and no one wants to pay for it. The designers are also committed to work in other projects and they do not have time to organise follow-up for a project which they might view as completed. One of the designers thought that follow-up is not very effective and it has to be done in the help of personal relationships. ‘Two years is long time and people forget easily what has been done.’ On the other hand, everybody does not have these personal relationships and people usually avoid all that is not necessary.

Hence systematic follow-up would be good. Everyone involved in project would gather around the same table and problematic issues would be discussed.

Conclusion:

- **Some kind of systematic project follow-up should be organised, so that mistakes are not repeated.**

4. EXPERIENCES AND OBSERVATIONS FROM PROJECTS IN KEMIRA ENGINEERING

In the second stage of the practical part, the general statements were rewritten for the case projects with the help of interviews of project personnel. The case projects were a fertiliser plant in Finland (project A) and a sodium percarbonate plant in Sweden (project B). The reason for the selection of the projects was their different scope and location. The fertiliser plant project was executed to modernise the process. The sodium percarbonate plant was a totally new plant and a new process for Kemira.

After formulation of the statements, the project personnel evaluated them. The case projects were compared to each other and conclusions about the success of the projects in utilising operational knowledge were made. Next the development plans will be introduced. Possible further study and analysis of the results have been introduced at the end of the section.

4.1 Case 1: Project A

The Kemira Agros complex fertiliser plant was built in the 1960s. Because of the age of the plant and demands of the market it was a time to modernise the plant. The conceptual design began in the beginning of 1997 and the investment proposal was approved in June 1997. Production in plant began in December 1998.

Persons, who were in the project, were interviewed to obtain information about the knowledge management of the project. The interviewees were the chairman of the steering group, the project manager, process designers, the automation designer, the development engineer, shift supervisors and the project co-ordinator. After formulation of the statements, they were sent to 19 persons. All except one responded to the statements.

4.1.1 Project scope and objective

The extent of the project was a renewal of the production room and equipment in the fertiliser plant. The reaction and gas washing departments were not included in the project. A new building was built next to the old plant.

The conceptual design was made in a separate project and the plant personnel did it almost completely. Basic design was made together with Kemira Engineering Oy and Kemira Agro Oy. In the detailed engineering stage, designers from outside Kemira were also involved.

The objective of the project was to fulfil today's requirements in

- working conditions
- safety
- capacity / number of different fertilisers / flexibility
- quality of product
- reliability of production

The most important new equipment were a granulation drum, dryer, screens, potassium mill, blower, cooler, cyclones, elevators, belt and screw conveyors. The old double shaft paddle mixer granulator and drying drum system was changed to a drum granulator and drying drum. The dryer and screens are bigger than earlier. Part of the equipment was connected to the old plant, which constrained layout and dimensioning.

The new equipment and layout improved working conditions as did the new control room with new furniture. The goal of the renewal of the automation system was to improve safety, flexibility, working conditions and to ensure the possibility of expanding the system in the future. The existing system was old and it was highly loaded. Because of the high load there was a risk of functional trouble. Dimensioning of the new equipment and the technical solutions conformed to new safety requirement.
The quality of the product improved when the granulation drum, dryer and screens were renewed. Quality control improved with the new automation system. The new automation system and dispensing equipment of raw materials also improved flexibility and the ability to change operation values when running the process.

Operability was improved by the new equipment and software in the control room. Modern process stations were added. These permitted a change in capacity and the possibility of developing the system in the future.

4.1.2 Process description

NPK-fertiliser consists of three main nutrients: nitrogen, phosphorus and potassium. In complex fertilisers there are different concentrations of these nutrients. In the Kemira NKP process, slurry from reactions with concentrated phosphate, nitrogen acid and ammonia is granulated and a compound of potassium is added /19/.

The production process of fertilisers has been introduced in Figure 7.

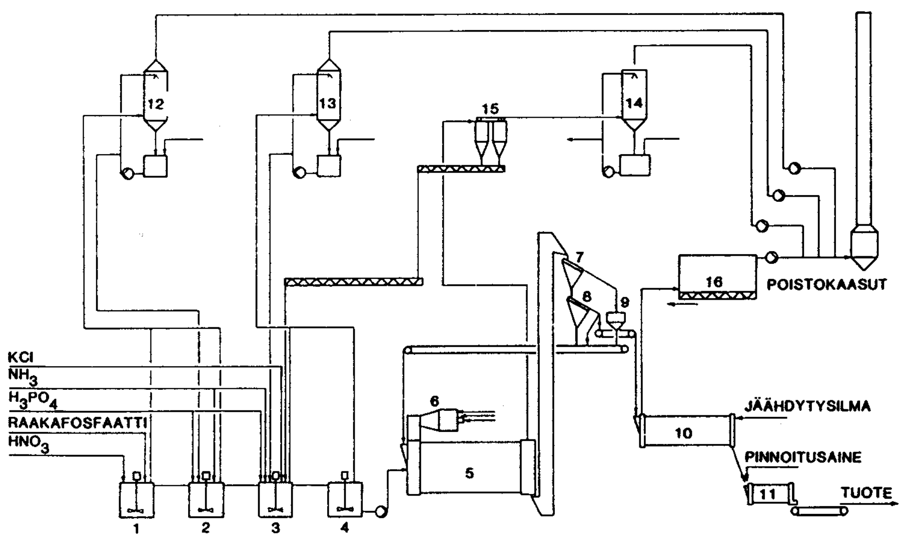


Figure 7 Kemira NPK fertiliser process /20/

Raw materials are fed to the reactors (1-3). Fertiliser slurry from the reactors is fed to the tank (4), which balances the flow to the granulation drum. Gases released from the reactor are washed in the scrubbers (12-14). The granulation and drying of the fertiliser slurry takes place in a combined granulation drum and dryer (5). Granules are dried to 0.5-1.5% moisture content and then they are fed to the screens (7-8). The size distribution of the granules in the product is 2-4 mm. When the granules are screened, too big granules go the crusher (9) and too little granules go back to granulation. A part of the product size granules are also recycled back to granulation. The production granules go to the cooler (10) and after that to the coating drum (11). The cyclones (15) are used to remove impurities from the gases which come from drier. Dust from the cooler and from the plant air is filtered in the tube filter (16). /20/

4.1.3 Project organisation

There was lot of people from the plant in the project organisation, which was exceptional. The majority in the process design group was operating personnel. The support group consisted of representatives from different parts of the plant, like the protection technician, foreman and the manager for reactor.

4.1.4 Project performance

All the objectives were not achieved. One deficit was working conditions (high temperature, lots of noise and dust). Actions to improve working conditions will be carried out in the future. The investment budget was exceeded by about 5 %. The budget overrun was caused by a variety of factors. The total schedule was kept, although some of the professional areas were late.

The problem in the project organisation was that process design group covered some of the same jobs as the support group. The job description of support group should have been defined more precisely. The tasks and objectives of the process design seemed not to be always clear. Process design was not completed on time, for example, the process description was late, which affected other professional areas and purchasing. In spite of this, the plant started on time. During the design process the person in charge of the process design was transferred to another project. As a whole, the project succeeded well.

After completion of the project, when the plant was already in operation, a feedback meeting was organised. Each group expressed its opinion about the project; what was successful and what could have been done better.

4.1.5 Analysis of comments

4.1.5.1 Operational knowledge in different design stages

The statements, the results and comments are shown in the appendices 5-10.

Operational knowledge was not utilised only in the detailed engineering phase. An operating person commented that operational knowledge was utilised in every stage. One designer noted that the basic design was made in co-operation with the operation experts. During the basic design stage over 20 meetings were held, where running practises were considered. Operational knowledge was applied most in the basic engineering and detailed engineering stages. In the project A, the operating personnel participated in the preparation of the initial investment proposal.

Conclusions:

- **Operational knowledge was utilised already in the conceptual design stage.**
- **Operational knowledge was utilised most in the basic and detailed engineering phases.**

4.1.5.2 Costs

The statements, the results and comments are shown in the appendices 5-10.

One reason for the increase in investment cost was that the operating personnel made late changes to the equipment. The piping cost increased, because operational knowledge about the condition of the pipelines was inaccurate. The operating cost decreased in the case of the new cooler.

‘The investment proposal was assumed to be the best available because it was made by people from the plant.’ ‘One of the participants was responsible for the production of fertilisers.’ A person from the steering group commented that the investment cost increased because of increased demands by the management and changes in prices. An operating person believed that the cost also increased because the wrong materials were used, for example in the chute after the granulating drum. The requirements of management had a bigger effect on the cost than changes made by operating personnel. One designer noted that the old dust pipes, which would have been preserved had to be changed because of their poor condition. The operating personnel did not notice or inform the designers of this. One designer noted that operational knowledge was not an adequate resource to minimise the operating cost. An operating person remarked that the new cooler decreased the operating costs. On the other hand, it is predicted that the operating cost will increase because of the bigger equipment. One of the operating personnel stated that maintenance did not express their needs or they had no needs. A person from the steering group commented that maintenance was not able to foresee the problems. The results contradict the general statements. It was believed that by operational knowledge could decrease costs.

Conclusions:

- **Investment cost was not decreased by utilising operational knowledge.**
- **Utilisation of operational knowledge decreased operating costs.**

4.1.5.3 Safety

The statements, the results and comments are shown in the appendices 5-10.

The operating personnel's comments and suggestions made it possible to achieve a proper safety level. Operational knowledge from other sites also led to the successful results.

The designers expressed the opinion that they have the final responsibility for safety. They did not believe that hazop is mostly based on operational knowledge. However, one of the operating personnel noticed that there were no designers in the Hazop analysis. Operational knowledge was very useful when designing single safe solutions but the overall solution is mostly based on the designers' theoretical knowledge.

Conclusion:

- **Operational knowledge improved the safety level of the plant.**

4.1.5.4 Environmental impacts

The statements, the results and comments are shown in the appendices 5-10.

The environmental impacts could not be affected remarkably by operational knowledge. Cleaning equipment did not belong to the scope. Probably, operational knowledge could have been utilised if a reduction in releases had been a primary objective in the design. The operating personnel was very eager to influence the design of environmental elements and cleaning equipment.

'Environmental impacts were anticipated to remain stable on the basis of operational knowledge'. One designer commented that the changes in the process did not affect environment problems. A person from the steering group commented that big changes in environmental impacts were not anticipated, but if necessary operating personnel has relevant knowledge especially about cyclones, dust filters and washing in scrubbers.

Conclusion:

- **Environmental impacts of the process remain stable on the basis of operational knowledge.**

4.1.5.5 Operability

The statements, the results and comments are shown in the appendices 5-10.

Operational knowledge of the suitability of construction material was usually utilised and it was usually used in the selection of equipment, too. The operating personnel noticed some of the bottlenecks in the process already during the design stage. The operating personnel's knowledge was used in the design of control system and thus process flexibility and reliability increased. The problems in process maintenance could not been predicted. The knowledge of the operating personnel is needed when the operation of fertiliser process is defined.

An operating person expressed that the choice of construction material for the granulation drum and the chute did not take into account operational knowledge. A person from the steering group expressed that during equipment selection, comments were hard to get or they were contradictory. Some bottlenecks were not foreseen or could not been avoided. Operational knowledge was not complete. The design of operability can not be totally based on operational knowledge. There were many operating persons in the automation group, which improved the flexibility and reliability of the control system. The equipment supplier defined some of equipment start-ups, something with which the operating persons disagreed.

The operating personnel had the greatest influence on operability. It is impossible to achieve high operability without operational knowledge.

Conclusions:

- **Operating personnel improved the operability of the process.**
- **The operating personnel did not foresee all the bottlenecks in the process during the design stage.**

4.1.5.6 Innovativeness

The statements, the results and comments are shown in the appendices 5-10.

Suggestions and ideas from the operating personnel increased the innovativeness of the design. The suggestions improved also the economics of the process.

A person from the steering group noted that many improvements were based on the ideas of the operating personnel. The cooler was a clear economical improvement and it was a suggestion from the operating personnel. The operating personnel presented that comments were hard to get from the field. Ideas came mainly from persons who were in the design group and from operational managers.

A meeting at which all operating persons are present should be organised after the investment proposal has been accepted. The investment plan would then be clear and the ideas would be documented and sent forward.

Conclusion:

- **Operational knowledge increased the innovativeness of the design.**

4.1.5.7 Schedule

The statements, the results and comments are shown in the appendices 5-10.

One reason for the delay in the process design was the changes demanded by the operating personnel. The operating personnel believed that a tight schedule restricted contacts between the operating personnel and the designers.

One designer noted that a realistic accurate schedule was made, but it was not followed. ‘Process design would have been delayed more if all the comments from the operating personnel had been taken into account.’ ‘Realistic comments might have been noticed.’ A person from the steering group said that the design phase would certainly have lasted longer if all the comments had been taken into account. At the same time it was noted that the operating personnel had difficulties understanding the drawings. Sufficient time should be allocated to the study of the drawings. One designer commented that the schedule was not so tight, but part of the group did not have experience of working in projects. Because of this lack of experience, tasks were not always done in the right way. Part of the operating persons also had their own daily job, in addition to work in the design group. Main designer joined another project in the middle of the design phase of the project.

As a conclusion can be said that if there had been no operational knowledge at all, the design phase would have taken much longer.

Conclusions:

- **Process design was late because the working methods were not the best conceivable.**
- **Operational knowledge management should be planned in the project.**

4.1.5.8 Problems in the utilisation of operational knowledge

The statements, the results and comments are shown in the appendices 5-10.

The operating personnel believed that physical distance between them and the designers caused problems in knowledge transfer. A designer commented that with today’s technology and working within one country’s boundaries distance could not be a problem in knowledge transfer. An operating person noted that the operating personnel was busy and the designers should be on site during the design. A person from the steering group commented that distance was a problem, but not crucial. Distance should not been considered a barrier to knowledge transfer.

Different project objectives caused problems during the design, according to the operating personnel. The designers did not think that the objectives were different. However, in the interviews it became evident that all the objectives were not same, for example the size of the control room. A steering group member commented that the basic objectives were the same but the working models were different. The process flow diagram and P&I diagram were given to the operating personnel too late for them to comment. The operating personnel stated that the diagrams were not available at all for comment.

Good relationships improved the design. A designer told that one's own activity helped to obtain information for the design.

Utilising operational knowledge in the design was not dependent on money and schedule but on the will to do so. Earlier, the operating personnel expressed the opinion that the tight schedule restricted contacts between the operating personnel and the designers. A designer noted that utilising operational knowledge can not depend on will alone- the will to use operational knowledge must always be found. A person from the steering group added that utilising operational knowledge is dependent on will and the ability to see how the plan affects the future of the plant.

Conclusions:

- **Operating personnel considered different things to be problems than designers.**
- **Good relationships helped in the utilisation of operational knowledge.**

4.1.5.9 Methods to improve the utilisation of operational knowledge

The statements, the results and comments are shown in the appendices 5-10.

Utilisation of operational knowledge and problems in co-operation between the designers and operating personnel should be discussed in project kick-off and feedback meetings more than today. The operating personnel believed that operational knowledge needs to be utilised more.

One of the designers commented that it is not easy to get operating personnel to take part in design. In addition, the collecting of operational knowledge should be organised and systematic. ‘It is difficult to make conclusions on the basis of contradictions and irrational thoughts.’ ‘Ideas should be processed into clear proposals, which are introduced to the project.’ The steering group members seemed to be pleased with the feedback meeting. They expressed that problems in co-operation were handled and documented. In the interviews it became clear that not all the operating personnel was satisfied to feedback meeting. ‘Everything did not come out in these meetings.’ One designer commented that operational knowledge was utilised well.

Conclusions:

- **Operational knowledge was plentiful during this project, but the utilisation of this knowledge should be organised.**
- **Utilisation of operational knowledge should be discussed in project kick-off and feedback meetings more than today.**

4.2 Case 2: Project B

Sodium percarbonate (SPC) is a white, granular and water-soluble chemical. It is a strongly oxidising substance and thus it is used as a bleaching and disinfecting agent. Traditionally, sodium perborate has been used as a bleaching chemical but because of its environmental impacts industry has turned using the sodium percarbonate.

The sodium percarbonate plant in Sweden was Kemira's first plant of this kind. The SPC plant project was carried out as a co-operation between Kemira Engineering Oy, Kemira Chemicals Oy and Kemira Kemi Ab. The reasons for the investment were that SPC markets are growing and the products fitted well into overall Kemira's strategy. The investment proposal was approved in September 1996 and the project started immediately thereafter. Production began in May 1998.

4.2.1 Project scope and objective

The plant was located in an old phosphoric acid plant. One of the raw materials, hydrogen peroxide, was transported by pipeline from the neighbouring H_2O_2 plant. Kemira bought the main equipment and basic engineering from Germany.

4.2.2 Process description

SPC can be produced by different methods. On the basis of pilot tests and the preliminary engineering, fluid bed spray granulation was chosen.

Sodium percarbonate is made from soda and hydrogen peroxide. The process contains two main steps, granulation and coating. The granulation of H_2O_2- and soda-solution is done in a continuous fluid bed. The coating is done in a batch type fluid bed. Final SPC can also be delivered uncoated. The process is illustrated in Figure 8.

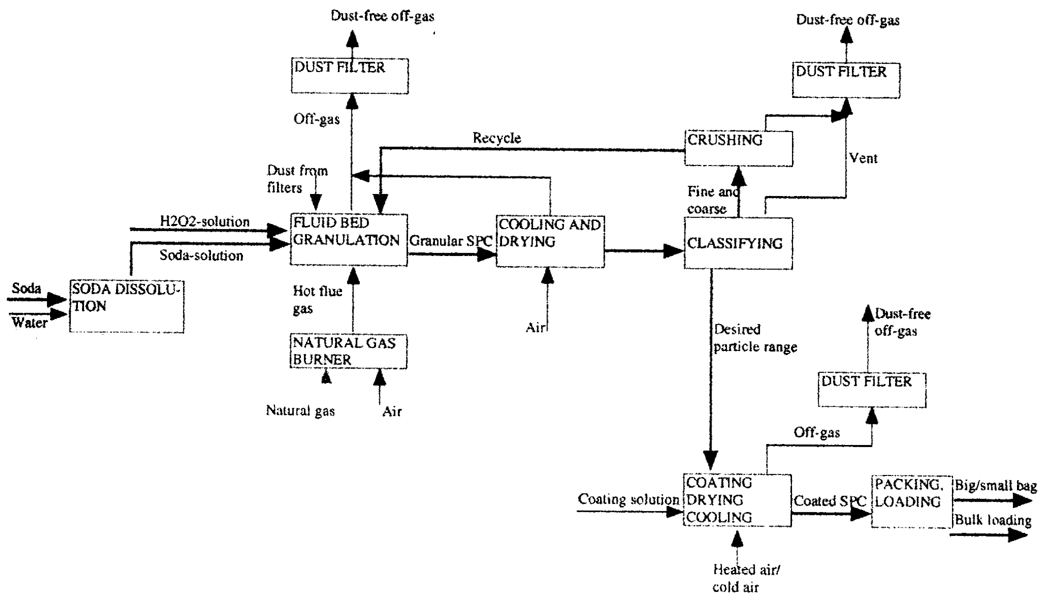


Figure 8 SPC production process

The main stages of the fluidbed spray granulation process are

- Soda dissolution.
- Continuous granulation in a fluid bed by spraying in soda solution and peroxide.
- Drying and cooling of granules.
- Coating of the SPC with subsequent drying and cooling.
- Packing of coated product.
- Recycle of under- and oversize granules.
- Gas cleaning.

4.2.3 Project organisation

Different organisations were responsible for engineering and start-up. The operating persons joined the project during start-up. The operating engineer joined the project before start-up. Engineering was mainly done in Finland in co-operation with the main equipment supplier. Swedish personnel were involved in technical support and also partly with the design.

4.2.4 Project performance

The cost estimate was exceeded due to the prolonged start-up and many late modifications. The schedule was kept. The main problems began at the start-up, where mechanical and process technical problems occurred. The biggest single problem was the dust, which could not be returned to the process as had been planned. If it is taken account that the SPC process is a new process, the project succeeded satisfactorily.

4.2.5 Analysis of comments

4.2.5.1 Operational knowledge in different design stages

The statements, the results and comments are shown in the appendices 11-14.

Operational knowledge was utilised in several stages of the design. Operational knowledge from other Kemira plants and from the equipment supplier was utilised in the design. The knowledge of the equipment supplier was insufficient. Operational knowledge is needed in next project.

The process designer told that operational knowledge was utilised from the start of the project. Operational knowledge was obtained from pilot plant trials, equipment suppliers and from other Kemira plants. He commented that the equipment supplier's operational knowledge was used, but it was not adequate. 'Operational knowledge from other Kemira plants, like knowledge about solid material handling, was utilised to some extent.' This know-how was not enough because troubles arose in the start-up. One designer believed that there was no operational knowledge available at all. In any future project the operating personnel will have gained valuable experience. 'Operational knowledge must be collected when starting the project and the operating persons could form a support group for project.' 'The right way of operation is to check with the operators.' Operational knowledge was utilised in every stage, but it was shown to be insufficient.

Operational knowledge can be utilised throughout the design. In the design of a new process like this, there is a lack of operational knowledge.

Conclusions:

- **In the beginning of the project, operational knowledge from outside the plant was utilised and at the end operating personnel's knowledge.**
- **There was not enough operational knowledge when designing a totally new process.**
- **Operational knowledge is considered to be necessary in the next project involving a similar process.**

4.2.5.2 Costs

The statements, the results and comments are shown in the appendices 11-14.

The investment cost estimate was inaccurate because not enough operational knowledge was available. Equipment costs increased compared to the investment proposal because the equipment supplier did not have enough operational knowledge. Utility cost was not affected by operational knowledge.

One designer noted that the cheapest equipment was chosen. Another designer expressed that there was initially a conflict between investment cost, operating cost and profitability. The investment cost would have been lower if there had been operational knowledge about the special features of this process during design.

Conclusion:

- **Investment cost increased, because no operational knowledge was available or it was inaccurate.**

4.2.5.3 Safety

The statements, the results and comments are shown in the appendices 11-14.

The operating personnel's suggestions improved the safety level. Operational knowledge from other sites was also utilised in safety decisions. In the safety analysis, operational knowledge was perhaps not utilised enough, although most designers believed it had been used adequately.

Operational knowledge from other sites (like hydrogen peroxide plants) was utilised in design of the peroxide system. The operating personnel believed they could not affect the safety analysis enough because part of the hazard analysis had already been done when they came to the plant. Opinions were listened to afterwards. One designer noted that the operators were at least involved in Hazop.

Operational knowledge about safety was mainly from other sites. Knowledge does not have to be process-specific.

Conclusion:

- **Operational knowledge improved the safety level of the plant.**

4.2.5.4 Environmental impacts

The statements, the results and comments are shown in the appendices 11-14.

The operating personnel believed that they could not affect the environmental impacts and would not be able to affect environment issues in any next project either.

The designers believed that operational knowledge of environmental impacts could be utilised. One designer expressed the opinion that operating persons have good knowledge of handling wastewater, washing etc. and also noise prevention. Another designer believed operational knowledge is essential in minimising the environmental impacts.

The operating personnel can probably affect the environmental impacts in a future more than they themselves believe. The operating personnel can not evaluate the situation in the future.

Conclusion:

- **Environmental impacts of the process could be affected by operational knowledge.**

4.2.5.5 Operability

The statements, the results and comments are shown in the appendices 11-14.

Operational knowledge was not utilised in the selection of equipment. The operating personnel's knowledge could not be used in design of the control system either. Process operability was increased (flexibility and reliability) by utilisation of operational knowledge.

A designer expressed the opinion that at the beginning there was no operational knowledge available. 'It was hardly possible to utilise operational knowledge in the selection of equipment, because the operators were not employed at that time.' 'Only little operational knowledge was available from pilot plant trials'. One designer noted that there were no comments from operating personnel during design of the control loops. ‘Now operating personnel has practical knowledge. ‘During start-up operational things were changed, especially in the process control system.’ ‘Operational knowledge is a key issue to be able to design and operate the plant well. ‘Flexibility and reliability are hard to carry out at the same time- Flexibility means quite a complicated structure, hard to keep reliability.’

In this project the operating personnel had the greatest influence on operability. In next project the effect of operational knowledge will be seen even more clearly.

Conclusion:

- **Operating personnel improved the operability of the process during the last part of the project.**

4.2.5.6 Innovativeness

The statements, the results and comments are shown in the appendices 11-14.

The operating personnel believed that suggestions and ideas from operating personnel increased the innovativeness of the process design.

A designer expressed that it was perhaps only a hope. In a new process the effect of operational knowledge to innovativeness is not so great as it is in well-known process. Innovativeness is based on experienced problems.

Conclusion:

- **Operational knowledge increased the innovativeness of the design, but not measurably.**

4.2.5.7 Schedule

The statements, the results and comments are shown in the appendices 11-14.

Process design would have taken longer if all the comments from the operating personnel had been taken into account. Listening to operating personnel and checking their ideas takes time.

Use of operational knowledge in next project will shorten its schedule; much more operational knowledge is available. The same mistakes will not be repeated and schedule will be shorter, especially start-up.

Conclusions:

- **Comments and suggestions from operating personnel involved risks of delay.**
- **Utilising operational knowledge in future projects will shorten their schedule.**

4.2.5.8 Problems in the utilisation of operational knowledge

The statements, the results and comments are shown in the appendices 11-14.

The operating personnel believed that the physical distance between designers, operating personnel and equipment supplier caused problems in knowledge transfer. They believed also that differences in the cultures of Sweden and Finland caused problems in the design process.

The designers commented that the distance was relatively short compared to many other projects and electrical mail was a constructive aid. ‘Distance was not a big problem’. ‘There was no structure to the training program. Staff members should have been more active during installation.’ Operators and plant manager were hired on time.’

Conclusions:

- **Designers and operating personnel saw problems in knowledge transfer differently.**
- **The long distance caused some problems in knowledge transfer.**
- **Different cultures may have caused problems.**

4.2.5.9 Methods to improve the utilisation of operational knowledge

The statements, the results and comments are shown in the appendices 11-14.

Discussion of utilisation of operational knowledge in a project kick-off meeting was not considered the best way to improve knowledge management. ‘The kick-off meeting is not the right place to discuss the details.’

Operational knowledge from the first plant can be utilised in the conceptual design of the next project. ’Now we have possibility to utilise operational knowledge.’ Operational knowledge needs to be utilised more than in this project. In the next project process design has a better base than in this case.

Conclusion:

- **Operational knowledge of the sodium percarbonate process can be utilised much more in the next project than in this case.**

5. COMPARISON OF THE TWO CASE PROJECTS

The two case projects were very dissimilar. The project A comprised of an old process and an old plant, whereas in the project B a new process and a new plant were built. Furthermore, project A was a domestic project, but B was an international (foreign) project. A lot of the operating personnel were involved from the beginning in the project A. The operating personnel entered the project B later. In the project A Kemira took care of the design of the whole process. In the project B the main equipment and basic engineering related to it was bought from outside Kemira.

In the project A operational knowledge was utilised more broadly than only in the detailed engineering. There was a large amount of operational knowledge available from the old plant as well as from other Kemira plants and it was utilised in all stages. In the project B operational knowledge available was far less and more would be needed. There was no operational knowledge from any Kemira plant in the beginning of the project.

In the project A, investment cost could not been decreased by utilisation of operational knowledge. Small improvements were achieved in operating costs, like reduction of energy cost because of new equipment. However, costs would have been higher in the project A if there had not been so much operational knowledge available. In the project B, costs would probably not have increased so much if operational knowledge about special features of the process had been available. Now the changes, which were necessity to improve the operability of the process, caused additional costs to the project. Generally, it was believed that costs could be decreased by utilisation of operational knowledge in these cases.

Safety was improved by utilisation of operational knowledge in both cases. Operating personnel were involved in the safety analysis. In the project A, operational knowledge from the plant and from other sites was utilised. In the project B operational knowledge came mainly from outside the plant, including the knowledge from suppliers and similar unit operations in other plants within the Kemira group.

In the project A, the environmental impacts were anticipated to remain stable on the basis of operational knowledge. In the project B, the operating personnel did not believe they were able to affect environmental impacts, something with which the designers disagreed. Utilisation of operational knowledge did not decrease the environmental impacts in both projects.

Process operability was increased by utilisation of operational knowledge in both cases. In the project A, the design of the control system was broadly based on operational knowledge. In the project B, operational knowledge was not utilised until the start-up. However, only a part of the problems could been solved by operational knowledge.

In both projects utilisation of operational knowledge increased innovativeness. When similar processes exist the effect of operational knowledge on innovativeness becomes more evident than with new processes.

In both cases process design would have been delayed more if all the comments from the operating personnel had been taken into account. On the other hand, the lack of operational knowledge or insufficient operational knowledge, delayed the start-up and thus the schedule of the project B. The project A would probably have lasted much longer if there had not been so much operational knowledge available.

The designers and operating personnel saw the problems in utilisation of operational knowledge differently. The operating personnel saw the long distance as a bigger problem than the designers. In the project B there were also cultural differences. In the project A the operating personnel felt that different objectives between the designers and operating personnel caused problems during design. In the project B the operating personnel thought that they were hired too late and therefore they were not able to affect the design.

In the project A the personnel considered that utilisation of operational knowledge should be discussed more in project kick-off meetings. In the project B the people involved expressed the opinion that the kick-off meeting is not the right place for that kind of discussion. Everybody felt that operational knowledge from the first plant can be utilised in the future. The project personnel stated that operational knowledge needs to be utilised more than was the case in these projects. In the project B the personnel was unanimous in this opinion.

6. KNOWLEDGE MANAGEMENT

6.1 Recognition of operational knowledge

Operational knowledge can be found from people who have taken part in the operation of the process, like process men, operators, workmen involved in process and maintenance, equipment suppliers, some designers etc. Because most of the operational knowledge is practical knowledge, it has been acquired by the senses, like seeing, hearing, feeling and smelling. Perceptions have been made during normal operation of the process, in emergency situations, in start-ups and shutdowns etc. Misleading conclusions, e.g. about the state of the process may be a problem. Because operational knowledge is usually empirical knowledge without a theoretical background, it is questionable whether it can be used in other circumstances.

Part of the operational knowledge is documented, for example, experiences of equipment suppliers, but a lot of information is recorded only in the memories of experienced operating personnel. Because operational knowledge changes with time, the most recent knowledge is not documented and is obtained only by communicating with people. Tacit knowledge is not documented either and thus it is often missed. Knowledge obtained directly from people should be emphasised more.

6.2 Methods of knowledge transfer

The two main methods of knowledge transfer are direct face-to-face knowledge transfer and indirect knowledge transfer with the help of different kind facilities and tools. Generally, face-to-face knowledge transfer is richer in the amount of information transferred than knowledge transfer through facilities and tools /21/. For example, a lack of belief or commitment, a defensive attitude, hope, enthusiasm and a host of other feelings that affect project performance can be detected in face-to-face knowledge transfer. Both methods are used in process design. Nowadays indirect knowledge transfer has increased because of the development of information technology applications. In spite of this, facilities and tools can not wholely replace human contacts.

Barriers to knowledge transfer also have to be recognised. A barrier can be an organisation or people or both. An organisation may have a structure which hinders knowledge transfer. People may be uninterested in listening or giving opinions, have a lack of awareness, be fearful giving opinions or averse to change etc. In particular, operational knowledge from the ‘field’ is hard to get. Long distance and cultural differences between people may cause problems in knowledge transfer. Facilities and tools of knowledge transfer may also create barriers or complicate knowledge transfer.

6.3 Application

Direct knowledge transfer can occur in a meeting among several people or between two people. When knowledge transfers along a chain from person to person misunderstandings can occur. Therefore knowledge transfer in a common meeting reduces mistakes and is very effective if certain information has to reach several people. Tight schedules of many projects may prevent contacts between persons.

Difficulties arise when different individuals have conflicting goals or when an individual’s objective is at odds with the primary objective of the meeting. For example some people use a meeting to avoid other work or to diffuse decision responsibility. The purpose and the scope of the meeting define who is invited. The list of participants should include those who can contribute towards the meeting’s goal. All participants have a responsibility to share relevant information and opinions, whether or not they have been directly asked. Assumptions, opinions and speculations offered in the meeting need to be checked against facts. Whoever has factual knowledge about the subject being discussed has a responsibility to verify or challenge assumptions, opinions and speculations. It is occasionally necessary to make sure that everyone understands and has the same understanding. When a subject is developed in a meeting, it is important to determine if the participants agree or not on its various aspects. At the end it is important to summarise the discussion /21/. One problem may be that an operating person lacks experience of working in projects.

Tools of knowledge transfer are computers, faxes, telephones etc. Written communication is one tool of indirect knowledge transfer. Telephone differs from other tools because it transmits some feelings. Computers allow many applications of knowledge transfer, like electronic mail, Intranet, databases etc. A project web site is quite a new application /22/. It ensures that everyone on the task force has the most-current information available. A project web site could be used for storing knowledge which is transferred in personal contacts.

Personal contacts are the best way to transfer knowledge if complicated subjects are handled or there is a danger of misunderstandings. In knowledge transfer through mechanical tools body language will be missed. It has been often expressed that more human contacts are needed. The applied method of knowledge transfer depends on the case. All project interactions do not require personal contacts /21/.

7. CONCLUSIONS

Designers and operating personnel consider the utilisation of operational knowledge to be important for process design. Operational knowledge is seen to affect mainly different details of design. However, many small details together affect measurably the end product.

The biggest benefit from utilisation of operational knowledge is obtained in the basic and detailed engineering stages of process design where the number of decisions made and the number of detailed facts are biggest. However, operational knowledge should be available already in the conceptual design stage. Utilisation of operational knowledge is dependent on the object of design- either a new or well-known process, or a modernisation of an existing plant.

Operational knowledge has different degrees of importance to each quality criterion of process design. Operational knowledge has the greatest influence on operability, safety and schedule of the design. Operability is mostly based on practical experience, for example the use of a control system. Working safety and ergonomics can be improved by the utilisation of operational knowledge about practices in the plant. Use of operational knowledge shortens the design schedule because everything does not have to be reinvented. The schedule may also be prolonged if knowledge management is not efficient. In many cases designers see the role and importance of operational knowledge differently than operating personnel.

The operating personnel often detects problems and needs for new solutions in the process and this may lead to an increase in the interest in innovative design. However, the operating personnel has to be active in the early design stages. Utilisation of operational knowledge can decrease costs if the operating personnel have long experience of different kinds of equipment and of operating different kinds of processes. Costs can also increase if knowledge management is not organised properly.

Environmental specialists are best able to evaluate the overall environmental impact, but the operating personnel can provide information about single emissions.

Generally, the utilisation of operational knowledge in the design improves the quality of the design. More emphasis should be set on the management of knowledge utilisation in design projects. This would help the designers and operating personnel to understand the objectives clearly.

The Delphi method as it was applied in this work proved to be a good way of getting opinions from designers and operating personnel. A larger number of iterative returns back to the respondents should have been carried out. This would have clarified the statements and prevented misunderstandings.

The following issues for further study were noticed during the work:

- definition of operational knowledge.
- reliability of operational knowledge.
- sources of operational knowledge.
- measurement of the quality criteria of process design.

8. RECOMMENDATIONS FOR KEMIRA

As a result of the interviews and analysis it was found that operational knowledge management is inefficient in Kemira, e.g. operating persons could not comment drawings because they did not get the drawings in time. Nevertheless, utilisation of operational knowledge in the case projects improved the quality of the process design, for example the operability of the process.

An improved procedure (knowledge management system) that would be followed in every project could be created. This would improve feedback from the operating persons to the designers. Feedback during design improves the quality of design and feedback after design can be used to improve the knowledge management process and information gained can be utilised in future projects. The system should describe the interface between the operating personnel and the designers and determine operating personnel’s role in the project. The operating persons have to be motivated and they have to understand the objectives and the meaning of design for their own work.

The following actions can be recommended:

1. General actions

Job rotation would increase the understanding and skills of personnel. Designers would be transferred to the operation temporarily and operating engineers to the design. For example, one designer would be transferred to the plant and one operating engineer would be transferred to a designer’s position.

Knowledge transfer between the support group (a group, which consists of operating personnel) and other project groups should be improved. Better knowledge transfer demands more joint meetings. Everybody has to have a clear function, which would prevent overlapping roles. Project manager takes care that all tasks are carried out, e.g., all drawings are transferred to the operation and they are commented on.

2. During design

All the persons in the project have to be aware of the special characteristics of the process and the project. In the design of a new process difficulties may appear which need special consideration. This could be informed in the kick-off meeting.

The operating personnel should be involved in the project not later than in the beginning of basic engineering stage. Thus situations when the operating personnel's comments have come too late can be avoided. Because opinions are hard to get from all operating persons, an occasion for them to comment should be organised. Alternatively, all operating persons could be interviewed personally if only a few people are involved.

Special meetings should be organised, where different kinds of preliminary drawings (block diagram, flow sheet, P&I diagram, layout) are commented on by the operating personnel. The results should be documented.

Utilisation of operational knowledge improves operability, but clear procedures for utilisation do not exist. Operability should be handled systematically, like safety. An operability analysis should be done by listing the objectives of operability. The operating personnel could comment on these and the comments would be documented in the early stages of design.

Because operational knowledge improves working safety and ergonomics, analysis of these areas should be organised separately. The operating personnel could participate in the preparation of the safety analysis concerning working safety and ergonomics.

Equipment design affects operability, safety and cost. A meeting for the operating personnel should be organised, where all the preliminary equipment design could be checked with the operating personnel.

A project web site or similar other system can be used to store the knowledge transferred in the above-mentioned meetings and analysis. By using the system, all the persons in the project would receive information in real time.

3. Post project

Project follow-up should be arranged. Feedback about utilisation of operational knowledge should be stored in written form in a database. Information gained from earlier projects should be checked at the beginning of the next project and used to develop the project.

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