

PREFACE

This report is the result of a market research project on the field reliability of plate heat exchangers in offshore oil and gas processes carried out by the author under the direction of Alfa Laval during September 2002 to September 2003.

The report is the final part of my Master Degree in Industrial Engineering and Management. The degree is awarded by Lund Institute of Technology, Lund University, Sweden.

I would like to thank all the employees within Alfa Laval who have contributed with their knowledge and support to this project. I would also like to thank the maintenance personnel and process engineers at the oil and gas companies who have provided valuable feedback.

I address a special thanks to my coach in this project, Tobias Svensson at Alfa Laval Oil & Gas Technology, for great support and dedication.

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Lund, December 2003



Lisa Rydén

Field reliability of plate heat exchangers in oil and gas processes

- a market perspective

By Lisa Rydén

ABSTRACT

In the offshore industry, reliability of installed equipment is of paramount concern due to safety, environmental and economic consequences. The costs of unplanned shutdowns and maintenance have high economic implications and are of increasing importance with tighter profit margins. Reliability is therefore of significance when selecting equipment model and brand.

This report presents a survey of the field reliability of Alfa Laval plate heat exchangers in offshore oil and gas processes with main focus on failure data. Because of the increasing attention paid to the relationship between optimised maintenance and the achievement of field reliability, preventive maintenance practices are also included in the survey. Whether a product is reliable or not is in the end determined by the users. The users attitudes regarding Alfa Laval reliability are therefore surveyed as well.

The method chosen was a cross-sectional survey focusing on quantitative primary data. Data was collected by using self-administered questionnaires distributed by e-mail to maintenance personnel and process engineers at offshore oil production platforms. Valid responses were received for a total of 174 installations, including 309 units at 60 platforms in nine countries.

For 65% of the surveyed installations, respondents reported no failures, 25% one failure and only 10% two or more failures. A total of 104 failures were reported. The average failure rate based on reported failures was estimated to 6,14 failures/10⁶ h. As a comparison, 114 failures/10⁶ h correspond to one failure a year. There is a risk that all failures have not been reported and the estimated failure rate should therefore be seen as some kind of minimum value. It should be noticed that findings of previous and related research indicate that in offshore oil and gas processes the estimated failure rate of plate heat exchangers are lower than the failure rate including all heat exchanger types.

Failure causes reported in the survey are generally the result of either none or incorrect maintenance, or unsuitable operating conditions which the survey have given many specific examples of. External leakage was the most commonly reported fault mode with 45% of the failures. This fault was generally due to gasket wear-out or gasket blow-out. Overall the most commonly reported corrective maintenance action

was replacement of a few or all plates (including gaskets). Recurring failures appear to be due to a lack of identifying the root cause of the problem, which can lie outside of the plate heat exchanger, leading to inappropriate corrective maintenance actions.

The majority of all reported failures, 56%, did not have any negative influence on the production process at the platform, only 16% of the failures were reported to have caused a process shutdown.

Maintenance practices vary broadly between the oil and gas companies and platforms but generally no or little preventive maintenance is carried out on the heat exchangers on a regular basis. Opening the unit for inspection, manual cleaning and the replacement of parts are most often only carried out on units that currently have or recently had failures.

Overall, the end users' attitudes and perceptions of the reliability of Alfa Laval and its products and support are very positive reflecting the few reported failures. 88% of the respondents consider the Alfa Laval plate heat exchanger to be a reliable or very reliable product.

Funktionssäkerhet hos plattvärmväxlare installerade i olja- och gasprocesser

- ett marknadsperspektiv

av Lisa Rydén

SAMMANFATTNING

Inom offshoreindustrin är funktionssäkerheten hos installerad utrustning av stor betydelse på grund av säkerhetsmässiga, miljömässiga och ekonomiska aspekter. Kostnaden för oplanerade stopp och underhåll har omfattande ekonomiska konsekvenser vilkas betydelse ökar med allt snävare vinstmarginaler. Funktionssäkerhet är därför av vikt vid val av typ av utrustning och leverantör.

Denna rapport behandlar en undersökning av funktionssäkerheten hos plattvärmväxlare levererade av Alfa Laval och installerade i olja- och gasprocesser. Fokus i undersökningen är feldata. På grund av det ökade intresset för sambandet mellan optimerat underhåll och en hög funktionssäkerhet så är förebyggande underhållsrutiner också inkluderat i undersökningen. I slutändan är det användarna av en produkt som avgör då funktionssäkerheten är tillräckligt hög. Användarnas uppfattning om funktionssäkerheten undersöks därför också.

Undersökningsmetoden var en tvärsnittsstudie med huvudsakligen kvantitativa primärdata. Data samlades in genom skriftliga enkäter distribuerade med e-mail till underhållspersonal och processingenjörer på oljeplattformar. Besvarade enkäter erhöles för 174 installationer, vilka inkluderar 309 enheter på 60 plattformar i nio länder.

För 65 % av de undersökta installationerna rapporterades inga fel, för 25 % ett fel och för 10 % två eller fler fel. Totalt rapporterades 104 fel. Den genomsnittliga felintensiteten baserat på rapporterade fel uppskattades till 6,14 fel/10⁶ timmar. Som en jämförelse kan nämnas att 114 fel/10⁶ timmar motsvaras av ungefär ett fel om året i genomsnitt. Det finns en risk att alla fel inte har rapporterats och den uppskattade felintensiteten ska därför ses som ett minimivärde. Det bör uppmärksammas att resultat från relaterade undersökningar indikerar en lägre felintensitet för just plattvärmväxlare än värmväxlare i allmänhet.

Med antagande om en bra design, är i undersökningen rapporterade felorsaker resultatet av inget eller felaktigt underhåll eller olämpliga driftsförhållanden vilka undersökningen gett många specifika exempel på. Externt läckage var den mest rapporterade typen av funktionsfel med 45 % av felen. Denna typ av funktionsfel var

generellt sett orsakad av packningsförslitning eller packningsförskjutning. Den mest rapporterade typen av avhjälpande underhåll var byte av några eller alla plattor (packningar inkluderat). Återkommande fel verkar bero på en brist att identifiera rotorsaken till felet som kan ligga utanför värmeväxlaren. Detta leder till olämpligt eller otillräckligt avhjälpande underhåll.

Majoriteten av alla rapporterade fel, 56 % hade ingen negativ inverkan på plattformens produktionsprocess, endast 16 % rapporterades ha orsakat ett stopp.

Underhållsrutiner varierar mellan de olika olja- och gasbolagen och plattformarna men generellt sett utförs ingen eller lite förebyggande underhåll på värmeväxlarna. Att öppna enheten för inspektion, manuell rengöring och byte av reservdelar utförs oftast bara på enheter som har eller nyligen har haft fel.

Användarnas uppfattning om funktionssäkerheten på Alfa Laval värmeväxlare var positiv vilket reflekterade att så få fel rapporterats. 88 % av de som deltog i enkäten ansåg Alfa Laval värmeväxlare vara tillförlitliga eller mycket tillförlitliga.

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1 INTRODUCTION

This chapter provides a brief introduction to the research project. The background, problem, objectives, scope and stakeholders of the research are presented. An overview of the report with brief details on the content of each chapter is also given.

1.1 Background

In the offshore industry, reliability of installed equipment is of paramount concern due to safety, environmental and economic consequences. The costs of unplanned shutdowns and maintenance have high economic implications and are of increasing importance with tighter profit margins. Reliability is therefore of significance when selecting equipment model and brand.¹

Alfa Laval has delivered plate heat exchangers (PHEs) for use in oil and gas processes to the offshore industry all over the world for more than 30 years. Their products are known for good design and manufacturing processes as well as advanced technology, all of which contribute to product reliability. But how is the equipment working in real life operational conditions? For Alfa Laval, as a supplier, data on both success and failure is necessary to evaluate their products' influence on the reliability of their customers' processes. A confirmation of field reliability would be an effective sales argument.

Reliability in the field is based upon practice in installation, operation and maintenance of equipment. Therefore, reliability field data must originate from end users and on-site maintenance records.² In most cases Alfa Laval does not receive any systematic feedback including reliability data.

1.2 Presentation of problem

Alfa Laval wishes to evaluate the field reliability of PHEs in oil and gas processes. In order to do this, data from the end users needs to be collected.

The task is therefore to carry out a survey of the field reliability of Alfa Laval plate heat exchangers in oil and gas processes through the collection and analysis of operational data from end users. Findings of previous and related research will also be reviewed.

The main focus of the survey is on failure data with the following specific questions:

- ✓ How common is the occurrence of failure for PHEs in oil and gas processes?
- ✓ What is the failure rate of Alfa Laval plate heat exchangers in offshore oil and gas processes?
- ✓ What are the most common fault modes and failure causes?

¹ www.oreda.com

² Cannon, A.G. & Bendell, A (Eds). (1991) *Reliability data banks*

- ✓ What do the operators do to correct the failures and what are the failures' influences on the processes?

Because of the increasing attention paid to the relationship between optimised maintenance and the achievement of field reliability the practice of preventive maintenance will also be included in the survey.

When is a product reliable enough? One way of answering this question could be: when the users of the product consider it reliable. Therefore the end users' attitudes regarding the reliability of Alfa Laval and its products and services were also surveyed.

1.3 Research scope

The survey will only include offshore, not onshore, installations. The reason is that this is a well-defined population. Borders between onshore plants in the oil and gas and associated industries, for example refineries, can be unclear.

Only process PHEs will be included in the survey. In this context, process PHEs are included in the topsides equipment on the platform, which are part of the oil production process and exclude small utility heat exchangers such as lube oil coolers. There are several motives for this limitation. Reliability of the process heat exchangers is much more critical than for utility heat exchangers. It is also very difficult to get reliable data on the utility heat exchangers because records are not usually kept.

1.4 Objectives

The main objective of this project is to evaluate the reliability of plate heat exchangers in offshore oil and gas processes, with main focus on failure data, through the collection and analysis of operational data from end users and by studying findings of previous and related research. An overall objective is to gain knowledge and understanding of the installed base and its users with focus on reliability and maintenance.

Detailed objectives:

- ✓ Create a common language for the concept of reliability within Alfa Laval Oil & Gas Technology
- ✓ Sharing of real life operational experience in a systematic way by creating a reliability database
- ✓ Exploring possible improvements of field reliability
- ✓ Provide input to marketing material such as case stories and technical paper
- ✓ Possibility of using the evaluation for benchmarking

1.5 Stakeholders

The major interest group for this research project are the employees at Alfa Laval Oil & Gas Technology and their sales representatives around the world. The intention is that this research will both add knowledge and be of practical use for this group. They can use collected data and this report to learn more about the concept of reliability and real life operational experiences. They can also find references to use for marketing purposes.

The oil and gas industry is another interest group who can learn more about reliability and maintenance of PHEs in oil and gas processes. There has been a demand from the market regarding this type of information.

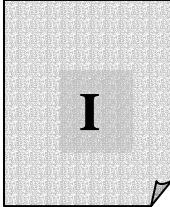
Stakeholders are also university students or other persons interested in market research projects, report writing or any issues covered in the report.

1.6 Overview of report

The six chapters of this report can be divided into four parts: I: Introduction, II: Framework, III: Method and IV: Findings. They are followed by References and Appendices. Appendix 1 is a collection of definitions of words that can be useful to know. The parts and chapters of the report and a brief description of their contents are presented on next page.

To get a complete understanding of the research project it is suggested to read all chapters in order. For those with lack of time and those who are mostly interested in the findings of the survey, Part I: Introduction and Part IV: Findings, should give sufficient information.

PART I

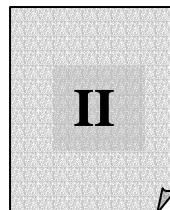


INTRODUCTION

Chapter 1: Introduction

The chapter provides a brief introduction to the research project. The background, problem, objectives, scope and stakeholders of the research are presented.

PART II



FRAMEWORK

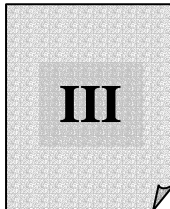
Chapter 2: Reliability theory

The purpose of this chapter is to put the research questions into a theoretical framework, which is used both in the choice of method and the interpretation of data. A definition of the term reliability is given. The need for reliability is discussed as well as how it is assessed and achieved.

Chapter 3: Survey environment

An overview of the complex environment of the research, which is important, both for the choice of method and in the development of conclusions. Alfa Laval, the offshore industry, the PHE and its market is presented. Previous studies in the field are also reviewed.

PART III

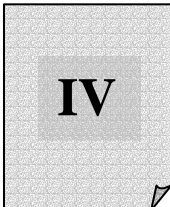


METHOD

Chapter 4: Method

In this chapter the research method is discussed and described. First the general basis for choice of method is presented. Next the survey procedure is described. Finally the reliability and validity of the research is discussed.

PART IV



FINDINGS

Chapter 5: Survey results

The purpose of the chapter is to present the results from the survey in an objective and meaningful manner. The chapter begins with a description of the characteristics of the surveyed units followed by the results in the specific areas of interest.

Chapter 6: Discussion and conclusions

The results for the specific areas of interest are discussed and conclusions are made based upon the results and research framework. An evaluation of the method and the project as a whole is also given.

2 RELIABILITY THEORY

The purpose of this chapter is to put the research questions into a theoretical framework, which will be used both in the choice of method and the interpretation of data. First a definition of the term reliability is given. Then the need for reliability will be discussed as well how it is assessed and achieved.

2.1 What is reliability?

The achievement and assessment of product and system reliability, in the form of continued existence or functioning, has been an implicit aspect of engineering practice since the earliest times.³ In order to discuss reliability issues in a meaningful way we need a definition of the term.

Reliability is defined as the “ability of an item to perform a required function under given conditions for a given time interval”.⁴ In other words it is the ability of an item to function without failures.⁵

Consequently, a failure is defined as “the termination of an item to perform a required function”.⁶ The reason leading up to a failure, called failure cause, “may be the result of one or more of the following: Design failure, manufacturing failure, installation failure, misuse failure, mishandling failure, maintenance related failure”. After failure the item has a fault.⁷

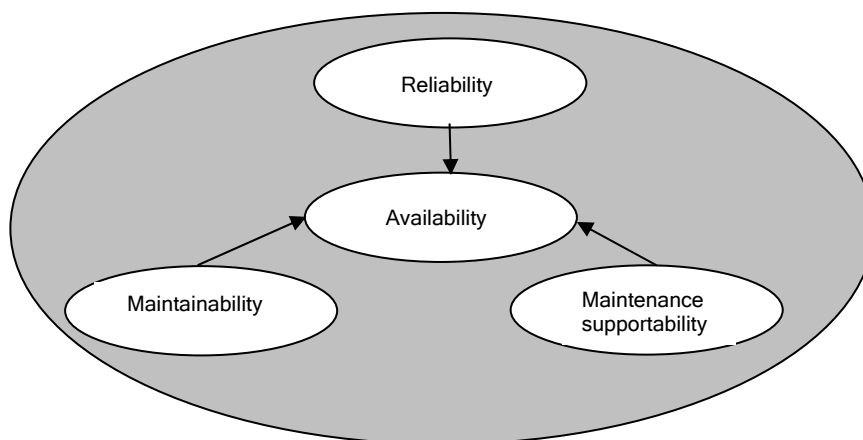


Figure 1 The dependability of an item is the collective term used for availability and its influencing factors; reliability, maintainability and maintenance supportability

³ Cannon, A.G. & Bendell, A (Eds). (1991) *Reliability data banks*

⁴ European Standard 13306:2001. *Maintenance Terminology*

⁵ Bergman, Bo & Klefsjö, Bengt. (1991) *Kvalitet från behov till användning*.

⁶ European Standard 13306:2001. *Maintenance Terminology*

⁷ Ibid

Reliability is an important factor in determining the availability and dependability of an item. Dependability is a “collective term used to describe the availability and its influencing factors: reliability, maintainability and maintenance supportability”, see figure 1.⁸

2.2 Why is reliability important?

Reliability issues are of concern both for users of products and manufacturers.

Customers and manufacturers often have some experience of the frustration and costs caused by poor product reliability. If a delivered product fails often, the manufacturer will suffer high warranty costs and the customers will suffer inconvenience. Outside the warranty period, only the customer suffers directly. In any case, the manufacturer is likely to suffer from loss of reputation, probably affecting future business negatively.⁹ Once gained, a reputation of unreliable products may be very difficult to correct.

Reliable products will lead to happy customers but what inconveniences do unreliable products cause their users?

Failures on equipment have negative consequences, e.g:¹⁰

- ✓ Reduced availability
- ✓ Reduced performance
- ✓ Influence on safety or environment
- ✓ Costs and loss of revenue

Therefore, for users of modern engineering systems reliability is of key concern. Interest in the study of reliability is a response to the need for finding answers to specific questions such as (adopted from Cannon, A.G. & Bendell, A (Eds). (1991) *Reliability data banks*) ...

- ✓ *How reliable is this system, or what is its probability of surviving a specified number of hours?*
- ✓ *Which is the most reliable of a number of possible designs for a system?*
- ✓ *Is it worth introducing redundancy into a design in case a component fails?*
- ✓ *How is the field performance of an item affected by its conditions of use?*
- ✓ *What will be the warranty, maintenance and logistic support costs for the system in the field?*
- ✓ *Can we improve the reliability and throughput of the system?*

⁸ Ibid

⁹ O'Connor, Patrick D.T. (1991) *Practical reliability engineering*

¹⁰ Hagberg, Leo & Henriksson, Tomas. (1994) *Lönsamt underhåll: 8 steg till säkrad produktion.*

In many cases, the answers to these questions will have important economic implications, for example those affecting availability of the system.

The costs of non-availability for many modern systems, particularly if unscheduled, can be very high e.g. for a radar station, a process plant or as earlier mentioned an offshore oil platform.¹¹ The costs are associated with repair, loss of income due to loss of production time and perhaps penalty costs. Reliability together with maintainability and maintenance supportability generally affects availability as seen in figure 1.

Today, there is an increased awareness of the high costs and loss of revenue for operation, maintenance and unavailability of systems/plants/components. The reliability of a system/plant/component has implications on several of these costs. Over the lifetime of a plant/system/component these costs are in many cases higher than the capital expenditures. This is one of the factors, which have increased the interest in the Life Cycle Cost (LCC) concept.¹²

Life cycle cost includes all costs associated with the procurement of a plant/system/component such as capital investment, operational costs, preventive and corrective maintenance costs and costs due to unavailability. Although life cycle cost analysis is used primarily as a tool for customers in evaluating quotations there are several other areas of use. For example, suppliers can use it when trying to convince a customer of the beneficial life cycle cost of the own product compared with the competition.¹³

2.3 Quantifying and evaluating reliability

While the need for products to be reliable is non-controversial, the quantification and evaluation of reliability is not. O'Connor states that "argument and misunderstanding begin when we try to quantify reliability values, or try to put financial or other benefit values to levels of reliability".¹⁴

He emphasizes that "quality and reliability data contain many sources of uncertainty and variability which cannot be rigorously quantified". Many of the factors arise because the involvement of people in making and using products. They are not made and used in exactly the same way. Other factors are due to the widely varying environments in which the same type of products can operate.¹⁵

Uncertainty is also introduced owing to variations in the definitions used. Two important problem areas are the failure definition and the component boundary definition. The failure definition is subject of interpretation and whether an event should be considered a failure or not thus becomes a subjective decision. Variations in the definition of the component boundary will also give way for variations in reliability

¹¹ O'Connor, Patrick D.T. (1991) *Practical reliability engineering*

¹² Ahlmann, Hans. (1993) *Service och underhåll*.

¹³ Ibid

¹⁴ O'Connor, Patrick D.T. (1991) *Practical reliability engineering*

¹⁵ Ibid

data. Questions such as: Should connecting pipes and valves be included in the component or not? need to be addressed.¹⁶

In order to achieve reliability some kind of value is needed in order to assess reliability performance, for example to choose between opposing designs and products and to assess the requirements for maintenance support and spare parts.¹⁷ A common way of specifying reliability values is as the rate of occurrence of failures denoted by λ , also called failure rate.

2.3.1 Failure rate definition

Rate of occurrence of failures or failure rate may be defined as the “number of failures of an item in a given time interval divided by the time interval”. Failure rate is generally a function of time i.e. the age of an item. “The failure rate function $\lambda(t)$ tells us how likely it is that an item that has survived up to time t , will fail during the next unit of time.”¹⁸ Mathematically, the failure rate may be defined as:

$$\lambda(t) \cdot \Delta t \approx \Pr(t < T \leq t + \Delta t \mid T > t)$$

T = time to failure

Δt = unit of time

The right hand side of the equation express the probability that an item, functioning at time t , will fail during the next time interval, $(t, t + \Delta t)$. The approximation is sufficiently accurate when the unit of time Δt is small.¹⁹

In reliability literature it is suggested that failure rate vary with time according to a bathtub shape, as the graph in figure 2. The model is based on the assumption that the life of an item can be divided into three phases; the burn-in phase, the useful life phase and the wear out phase. In the beginning of the burn-in phase the number of failures may be high due to installation problems, inherent quality problems or other initial complications. Failure rate is usually decreasing as problems are solved. During the useful life phase the failure rate is typically constant with failures being externally induced, for example maintenance-induced failures of mechanical equipment. The wear out phase is characterized by an increasing failure rate as wear out of parts is increasing.^{20 21}

¹⁶ Cannon, A.G. & Bendell, A (Eds). (1991) *Reliability data banks*

¹⁷ Ibid

¹⁸ OREDA, *Offshore Reliability Data*. (2002)

¹⁹ Ibid

²⁰ Ibid

²¹ O'Connor, Patrick D.T. (1991) *Practical reliability engineering*

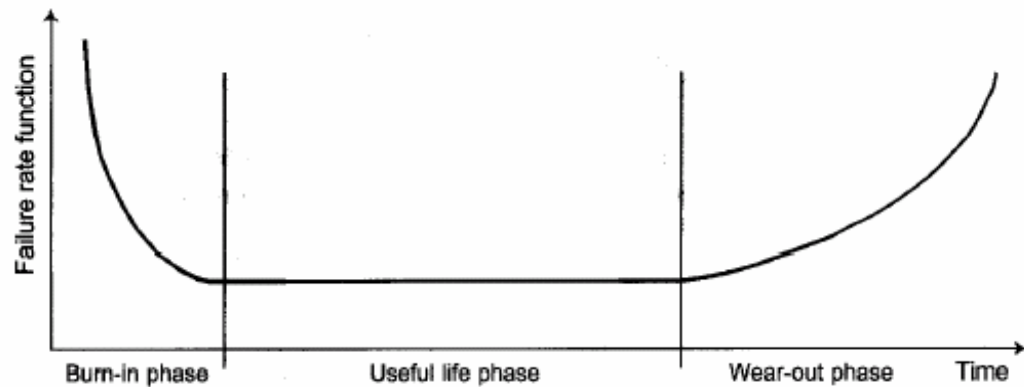


Figure 2 The failure rate bathtub curve²²

2.3.2 Estimation of failure rate

In the useful life phase where the failure rate is close to constant and independent of time, the failure rate function, $\lambda(t) = \lambda$. This relationship is used when estimating average failure rate for a number of items.²³

Assuming a constant failure rate, the estimated failure rate, λ , can be calculated as:²⁴

$$\lambda = \text{Number of failures} / \text{Aggregated time in service} = n / \tau$$

Aggregated time in service is usually expressed in 10^6 hours and consequently failure rate is expressed in number of failures per 10^6 hours.

The time of reference for aggregated time in service may be calendar time or operational time. Expressed in calendar time, the aggregated time in service is the interval of time between the start-up of the installation and the collection of data. The operating time is the total time the installation is in operation e.g. not out of service due to maintenance or repair.²⁵

Calendar time could be used instead of operating time when appropriate. Then trend analysis and failure rate estimates would be calculated on a calendar time basis. This is acceptable if run time is quite closely correlated with calendar time and if operating data is not easily obtainable. Using calendar time can be easier and cheaper. Only the start-up date for each unit and the total number of units in use need to be ascertained.²⁶

The uncertainty of the estimated failure rate value in relation to the true value may be presented by a confidence interval. The confidence interval is the interval between the

²² OREDA, *Offshore Reliability Data*. (2002)

²³ OREDA, *Offshore Reliability Data*. (2002)

²⁴ Ibid

²⁵ O'Connor, Patrick D.T. (1991) *Practical reliability engineering*

²⁶ Ibid

lower and upper s-confidence limits. For a 90% confidence interval the true value is covered by the interval with a probability of 90%.²⁷

Assuming a constant failure rate, the failure rate data will be exponentially distributed and thus highly skewed. Under these circumstances the χ^2 distribution is used for estimating the confidence limits in these circumstances.²⁸

With n failures during an aggregated time in service τ , the 90% confidence interval is given by:

$$\left(\frac{1}{2\tau} * z_{0.95, 2n}, \frac{1}{2\tau} * z_{0.05, 2(n+1)} \right)$$

where $z_{0.95, v}$ and $z_{0.05, v}$ denote the upper respectively lower confidence limits of the χ^2 distribution with v degrees of freedom.²⁹

The formula given above for estimated failure rate is valid under the assumption of a so-called homogenous sample or for individual items. A homogenous sample means that all the items included are the same type of item operating under the same conditions. In many cases we do not have a homogenous sample i.e. we know that there is variation between sub-samples within the sample. In these situations we may decide to merge several more or less homogenous samples, into what we call a multi-sample. The estimation of an average failure rate for a multi-sample, needs a more advanced procedure than the formula *, in order to compensate for the variations. This procedure will not be given here but for those who are interested a rationale for the procedure is presented in the reference, *OREDA, Offshore Reliability Data*. (2002).³⁰

2.3.3 Critique of the assumption of a constant failure rate

The estimation of an average failure rate requires the assumption of a constant failure rate. The assumption of a constant failure rate is based on the view that any repairable system may be considered as an assembly of parts, the parts being replaced when they fail. If part times to failure are independently and identically exponentially distributed (IID exponential) the system will have a constant failure rate.³¹

However, the assumption of IID exponential for part times to failure in a repairable system, and therefore the assumption of a constant failure rate, can be very misleading. Some reasons for this are (adopted from O'Connor, Patrick D.T. (1991) *Practical reliability engineering*) :

- ✓ *Failure and repair of one part may cause damage to other parts. Therefore times between successive failures are not necessarily independent.*
- ✓ *Repairs do often not renew the system. Repairs are often imperfect or they introduce other defects leading to failures of other parts.*

²⁷ *OREDA, Offshore Reliability Data*. (2002)

²⁸ O'Connor, Patrick D.T. (1991) *Practical reliability engineering*

²⁹ *OREDA, Offshore Reliability Data*. (2002)

³⁰ *OREDA, Offshore Reliability Data*. (2002)

³¹ O'Connor, Patrick D.T. (1991) *Practical reliability engineering*

- ✓ *Repair personnel learn by experience, so diagnostic ability (i.e. the probability that the repair action is correct) improves with time. Generally, changes of personnel can lead to reduced diagnostic ability and therefore more reported failures.*
- ✓ *Not all part failures will cause system failures*
- ✓ *Factors as on-off cycling, different modes of use, different system operating environments or different maintenance practices are often more important than operating times in generating failure-inducing stress.*
- ✓ *Reported failures are nearly always subject to human bias and emotion. What an operator or maintainer will tolerate in one situation might be reported as a failure in another, and perception of failure is conditioned by past experience, whether repair is covered by warranty, etc. Wholly objective failure data is very rare.*
- ✓ *Failure probability is affected by scheduled maintenance or overhaul. Systems, which are overhauled often, display higher failure rates shortly after overhaul, due to disturbance of parts, which would otherwise not have failed.*
- ✓ *Many reported failures are not caused by part failures at all, but by events such as intermittent connections, improper use, maintainers using opportunities to replace 'suspect parts', etc.*

There are certainly more to be added to this list. So, why is the constant failure rate assumption so often used considering all these problems? O'Connor states it is because it is practicable and measurable, "particularly when data are not sufficient to allow a more detailed analysis". Sufficient reliability data is very difficult and expensive to acquire.³²

2.3.4 Other ways of evaluating reliability

Under the condition of a constant failure rate, repairable systems reliability performance is sometimes expressed as the *mean time between failures* (MTBF) which is calculated as, $\lambda = (\text{MTBF})^{-1}$.³³

MTBF is often used when illustrating the relationship between availability and its influencing factors:

$$\text{Availability} = \text{MTBF} / (\text{MTBF} + \text{MTTR} + \text{MWT})$$

where MTTR (*mean time to repair*) is the measure of maintainability and MWT (*mean waiting time*) is the measure of maintenance supportability:³⁴

Note that this is the simplest steady-state situation based on a constant failure rate. From studying the formula it is clear that improvements of reliability can be achieved by improving MTBF, MTTR or MWT. It is important to be aware of the trade-offs

³² O'Connor, Patrick D.T. (1991) *Practical reliability engineering*

³³ *Ibid*

³⁴ Ahlmann, Hans. (1993) *Service och underhåll*.

between these factors and the total effect on the availability. For example new and faster repair routines may increase MTTR at a cost of a slight reduction in reliability.³⁵

Due to the many uncertainties involved in estimating reliability values, the benefits of such a measurement could be and have been questioned. Warrington and Jones criticize the use of failure rate and MTBF as measure of reliability performance. They argue that reliability and maintenance are not direct customer requirements in its own right and therefore not meaningful to express in absolute values.³⁶

Customer requirements are rather concerned with the benefits that reliability and supportive maintenance can deliver, described in previous section. Generally these benefits are maximisation or minimisation of scenario objectives such as safety, operational success and whole-life costs. For these reasons reliability and maintenance should rather be expressed in terms of the benefits they can deliver in the context of a full scenario and not as a numerical measure. It is important to notice that all benefits do not have the same priority or criticality for all customers. Therefore a structured process is needed to find the single best technical solution for each customer.³⁷

2.4 Principles of achieving product reliability

Reliability is concerned with failures throughout the life of a product. Naturally the achievement of reliability then starts when designing and developing a product. Decisions made during the design phase will strongly influence the future reliability of a product. This will not affect only one item but all items produced. In order to create a good design the designer/s must have a wide range of knowledge including materials, processes, components, production methods and more. Computer-aided engineering (CAE) may assist in many design tasks and can, properly used, contribute to more reliable designs.³⁸

The next step of achieving reliability is well-controlled manufacturing processes. Poor quality of production can make a well-designed product unreliable. Control of production quality involves controlling and minimizing variability and identifying and solving problems. Variability in production processes is the main cause of production-induced unreliability. Human operations are frequent sources of variability, particularly if repetitive or boring. Quality control (QC) methods and statistical process control are used in measurement, control and minimization of variability.³⁹

There is a lot more to be said about the achievement of reliability in design and manufacturing, but this report is neither about good design nor well-controlled manufacturing processes. The focus here is on reliability in the field. Assuming a good

³⁵ O'Connor, Patrick D.T. (1991) *Practical reliability engineering*

³⁶ Warrington, Les & Jones, Jeffery A. (2003) *Derivation of Technical Reliability & Maintenance Requirements for Maximised User Benefits*. 2003

³⁷ Warrington, Les & Jones, Jeffery A. *Derivation of Technical Reliability & Maintenance Requirements for Maximised User Benefits*. 2003

³⁸ O'Connor, Patrick D.T. (1991) *Practical reliability engineering*

³⁹ Ibid

design and well-controlled manufacturing processes, product reliability in the field is based upon good practice in installation, operation and maintenance of equipment.⁴⁰

Good practice in installation, operation and maintenance requires a good knowledge of the equipment and how to handle it. Operating and maintenance instructions from the supplier may improve this knowledge. Users learn by experience and knowledge generally increases with time. Conversely, frequent changes of personnel can lead to loss of knowledge. Established routines and maintenance records will prevent this loss.

Another factor affecting reliability in the field is redundancy. Redundancy means that there is parallel equipment and the required function can therefore be maintained, in case one of the equipment units fails.⁴¹

2.4.1 Maintenance and the achievement of reliability

The relationship between optimized maintenance and the achievement of field reliability attracts increasingly attention. Maintenance activities used to be regarded as a necessary evil, only inducing costs and disturbance. Today there is awareness that these activities in fact can reduce total cost and increase profit.⁴²

With a suitable maintenance strategy, maintenance provides an essential contribution to the reliability and dependability of an item.⁴³ At the same time reliability data can be used to predict how maintenance will affect failure rate and by doing so be of use in maintenance optimization.⁴⁴

Maintenance activities are usually divided into corrective maintenance and preventive maintenance. Corrective maintenance is the “maintenance carried out after fault recognition and intended to put an item into a state in which it can perform a required function”.⁴⁵ If the failure is serious, corrective maintenance has to be carried out immediately, without delay after fault recognition. Failures needing immediate action can be very costly because of the costs of unplanned shutdowns apart from the direct maintenance costs. All failures do not need immediate attention and corrective maintenance may then be delayed, i.e. until a planned shutdown.

Preventive maintenance is the “maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure”.⁴⁶

⁴⁰ Cannon, A.G. & Bendell, A (Eds). (1991) *Reliability data banks*

⁴¹ Hagberg, Leo & Henriksson, Tomas. (1994) *Lönsamt underhåll: 8 steg till säkrad produktion*.

⁴² Ahlmann, Hans. (1993) *Service och underhåll*.

⁴³ European Standard 13306:2001. *Maintenance Terminology*

⁴⁴ Langseth, H et al (1998) “Analysis of OREDA data for maintenance optimization”.

⁴⁵ European Standard 13306:2001. *Maintenance Terminology*

⁴⁶ Ibid

There are several objectives of preventive maintenance, for example:

- ✓ Minimize failures and their negative consequences
- ✓ Minimize maintenance induced shutdowns
- ✓ Increased lifetime of equipment and components
- ✓ Better spare part holdings
- ✓ Better documentation contributing to continuity of maintenance activities.

Examples of preventive maintenance activities are cleaning, replacements of parts and lubrication. Examples of how failures are minimized and costs saved are: a) cleaning of the equipment preventing failure that would cost a lot more to correct and b) replacing components at scheduled shutdowns which reduces the risk of part failure, requiring a more expensive unplanned shutdown for replacement.⁴⁷

The preventive maintenance can be either predetermined in accordance with established time intervals or condition based i.e. based on performance and/or parameter monitoring. Condition based maintenance is increasingly replacing the practice of predetermined maintenance which has shown to be neither technically nor economically successful. Condition based maintenance leads to longer intervals between maintenance operations and reduced maintenance costs. The increasing popularity is also due to the recent development of devices for monitoring performance and parameters.⁴⁸

In order to optimize preventive maintenance, all effects and costs of the maintenance activities must be considered. Sometimes it will be more economical to wait with replacement until a part fails than before, for example when repairs introduce defects leading to failure of other parts. An example of this is given below.⁴⁹

“Data might show that a high pressure hydraulic hose has an increasing hazard rate after a failure-free life, in terms of hose leaks. A sensible maintenance policy might therefore be to replace the hose after say, 80 per cent of the failure free life. However, if the replacement action increases the probability of hydraulic leaks from the hose end connectors, it might be more economical to replace the hoses on failure.”⁵⁰

Frequent overhaul and maintenance can cause disturbance of parts resulting in failure. Systems that are overhauled often display higher failure rates shortly after overhaul.⁵¹

⁴⁷ Ahlmann, Hans. (1993) *Service och underhåll*.

⁴⁸ Ahlmann, Hans. (1993) *Service och underhåll*.

⁴⁹ O'Connor, Patrick D.T. (1991) *Practical reliability engineering*

⁵⁰ Ibid

⁵¹ Ibid

3 SURVEY ENVIRONMENT

The chapter gives an overview of the complex environment of the research, which is important, both for the choice of method and in the development of conclusions. Alfa Laval, the customers, the product and the market is presented. After that previous studies in the field are reviewed.

3.1 Alfa Laval - the supplier⁵²

Alfa Laval, a Swedish company founded in 1883, is a global supplier of products and system solutions based on their key technologies heat transfer, separation and fluids handling. The company is active in more than 100 countries and currently has about 10 000 employees. The headquarter is located in Lund, Sweden.

Alfa Laval customers are to be found in a wide range of industries. The total invoicing in 2001 was 1,700 MEUR.

3.1.1 Sales organization

The sales organization is divided into customer segments, grouped into the two divisions, Equipment Division and Process Technology Division.

Each customer segment is divided into two or three market units targeting specific customer groups within the segment. Each market unit is responsible for the marketing and sales of Alfa Laval products and system solutions globally to their group of customers.

The fully incorporated Alfa Laval sales companies located in 50 countries worldwide manages direct sales. A central market unit supports the local sales companies in both technology and market related issues. It is also the link between the market/sales companies and the R&D, product management and operations within Alfa Laval.

The after sales organization Parts & Service has a central global service network as well as local service centres and field engineers. They sell spare parts and service contracts and provide any service for the Alfa Laval products.

3.1.2 Market Unit Oil & Gas Technology

Market unit Oil & Gas Technology is part of the customer segment Energy and Environment, which is part of the Process Technology Division. Organization charts are presented in figure 3 and figure 4. The market unit is responsible for the marketing and sales of Alfa Laval products and system solutions to the oil and gas industry globally.

⁵² All information in this section has been provided by employees at Alfa Laval Oil & Gas Technology and the website www.alfalaval.com

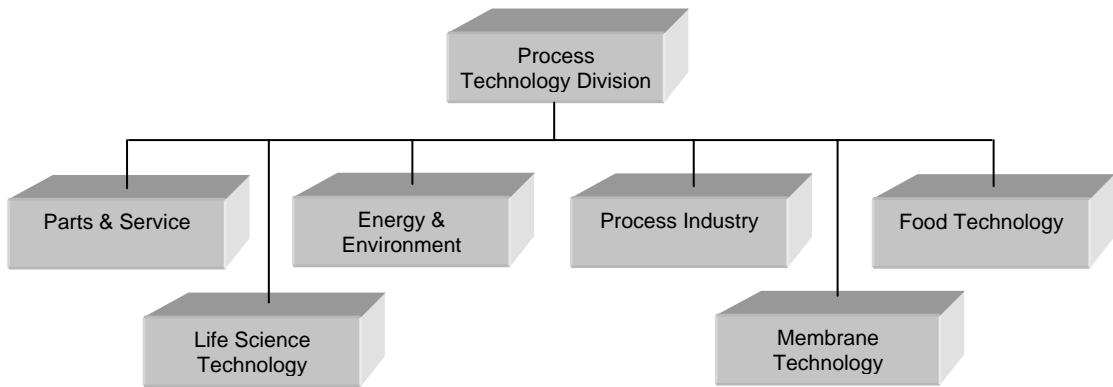


Figure 3 Process Technology Division organization chart

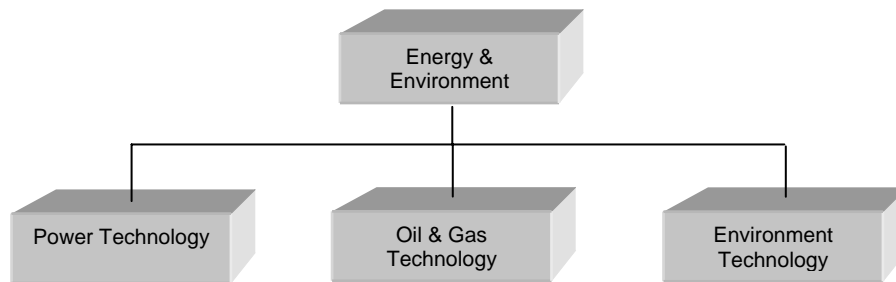


Figure 4 Energy & Environment customer segment organization chart

The end users of the products and systems are found all over the world in upstream offshore and onshore operations and include all major oil companies, for example BP, ConocoPhillips and Statoil. Sales are conducted either directly to the oil and gas company or through a contractor, package builder or service company. Figure 5 presents the possible sales alternatives.

For market unit Oil & Gas Technology the plate heat exchanger is a core product, which stands for a substantial share of the sales. Heat exchangers in oil and gas exploration and production are mainly used for cooling of machinery (utility coolers) and for the initial treatment of extracted oil and gas. The heat exchangers used in the treatment of the extracted oil and gas are called process heat exchangers and is part of the topsides equipment on the platform.

The process heat exchangers are used in a variety of oil and gas processes for cooling, heating, condensing, reboiling and vaporizing. Main processes are crude oil dehydration, gas compression, gas dehydration, gas sweetening and secondary cooling.

Plate heat exchangers are sold both to new plants and for replacements of old heat exchangers. Each plate heat exchanger is designed to suit the specific application and process conditions.

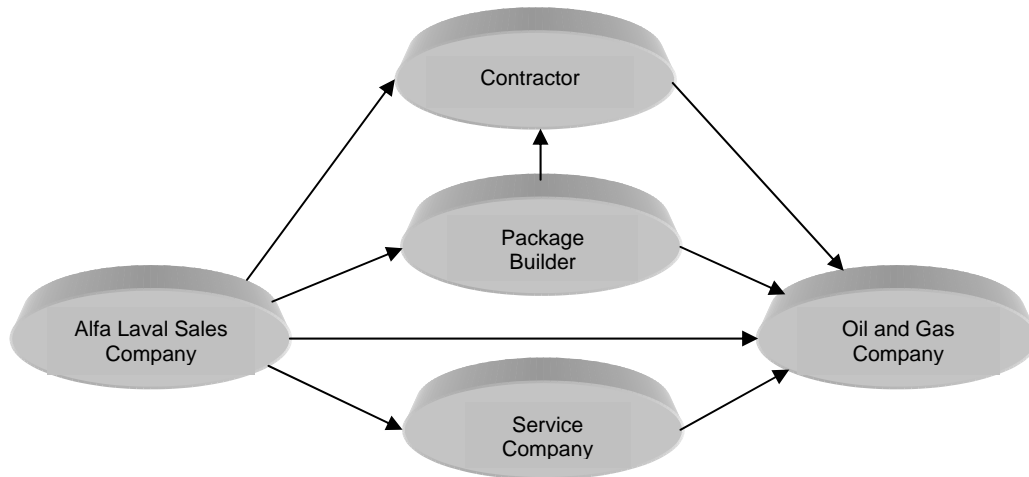


Figure 5 Alfa Laval sales process to oil and gas customers

Today, Alfa Laval has delivered several thousands of plate heat exchangers to the oil and gas industry. A majority of these are recorded in an installation database with facts on location, end user, duty and design parameters. Oil & Gas Technology now records all deliveries in this database. This has not been a priority in the past though, which is why a part of the delivered units are missing in the database.

3.2 The offshore industry – the operators

The operator group in focus of this survey is the offshore oil and gas production platforms. Offshore oil production accounts for about 30% of the total world oil production, and offshore gas production for about half of the world production of natural gas.

There are about 8000 offshore oil and gas platforms worldwide. About half of these are in the US. Examples of other important areas are the Middle East, North Sea and Brazil. The distribution of platforms is shown in figure 6.⁵³ However, the size and production rate of the platforms in the different regions vary. For example an offshore oil field in Norway generally has a daily oil production many times the production of large offshore fields in US.⁵⁴

⁵³ www.mms.gov

⁵⁴ Ostebo, Runar. (1993) *System-effectiveness Assessment in Offshore Field Development using Life-cycle Performance Simulation*.

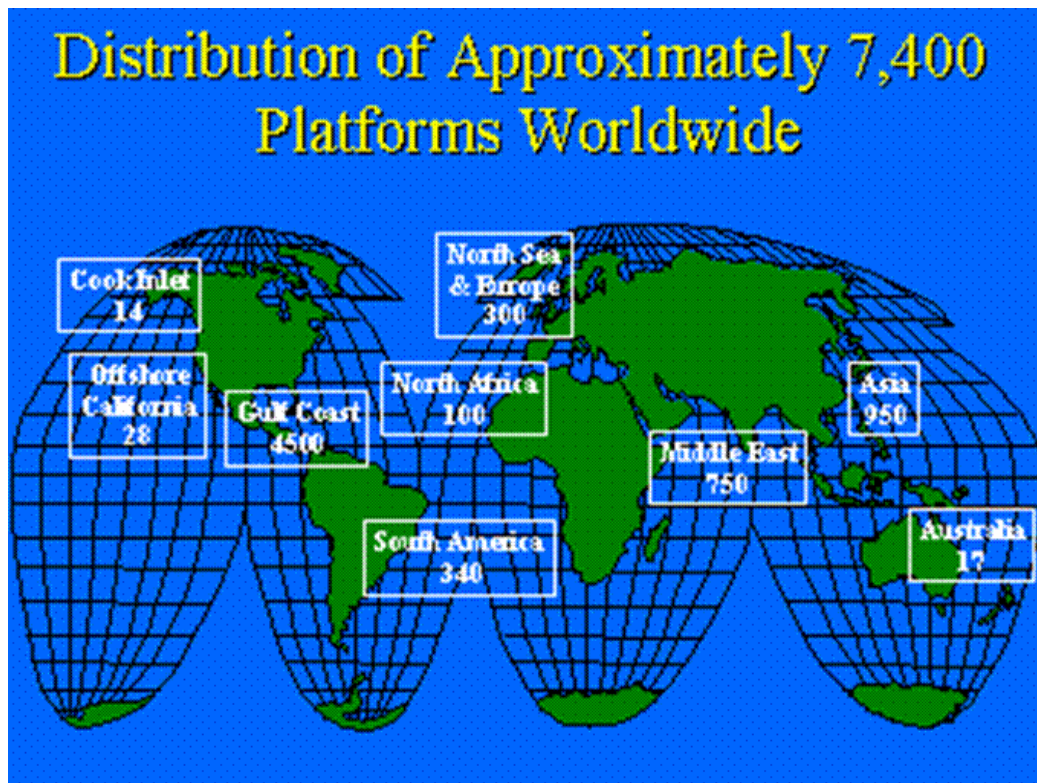


Figure 6 Distribution of approximately 7400 platforms worldwide⁵⁵

The offshore industry is dominated by relatively few major oil and gas companies. The market has gone through a consolidation in recent years. Examples of mergers are BP and Amoco, and Exxon and Mobil.

3.2.1 Reliability in the offshore industry

“The reliability, availability, maintenance and safety (RAMS) of offshore exploration and production facilities are of considerable concern to employees, companies and authorities.”⁵⁶ “Equipment faults alone, or in combination with other factors, have been the cause of a number of accidents.”⁵⁷

For oil companies, unavailability in large offshore fields has high economic implications, e.g. maintenance costs and costs associated with unplanned shutdowns such as inability to meet the demand for deliveries. This makes reliability issues of key

⁵⁵ www.mms.gov

⁵⁶ OREDA, *Offshore Reliability Data*. (2002)

⁵⁷ www.oreda.com

concern for economic decision-making, both during planning and production phases.⁵⁸

There is a trend towards life-cycle assessment i.e. more focus is put on operating expenditures in addition to capital expenditures, which traditionally has been the most important factor. Decisions taken at an early planning stage will strongly influence the total life-cycle cost. Maintenance requirements are dependent on decisions regarding equipment choice and design in the planning stage. Maintenance costs are a big part of the total operating costs. As an example, for one North Sea operator, approximately 60% of the offshore operational costs are related to the maintenance of the platform.⁵⁹

Various types of RAMS analyses are carried out to provide a basis for decisions in offshore engineering, fabrication and operations. It is a support when optimizing the production system and identifying critical issues to be followed up in later project phases. Analyses are also used in improving existing facility operation. In order to allow RAMS analyses to be conducted, a source of real life reliability data is required.⁶⁰

In response to the need for reliability data the OREDA (Offshore RELiability DAta) project organization was established in the early 1980's by eight major oil companies operating in the North Sea and Adriatic Sea. The members of OREDA are (as per 2002) ENI/AGIP, BP Exploration, ExxonMobil, Norsk Hydro, Phillips Petroleum, Statoil, Shell Exploration & Production and TotalFinaElf. SINTEF has been the main contractor for project management since 1990.⁶¹

“The main objective of the OREDA project is to contribute to an improved safety and cost-effectiveness in design and operation of oil and gas exploration and production facilities; through collection and analysis of maintenance and operational data, establishment of a high quality reliability database, and exchange of reliability, availability, maintenance and safety (RAMS) technology among the participating companies.”⁶² One of the overall objectives of collecting data is for the selection of most reliable make/model of equipment.⁶³

Findings from the OREDA project will be presented in Section 3.5.

Despite the many risks and uncertainties associated with the oil and gas industry, involving the risk of huge financial losses, poor decision-making has plagued the oil and gas investors since the industry's inception, leading to monumental and recurring mistakes.

⁵⁸ Ostebo, Runar. (1993) *System-effectiveness Assessment in Offshore Field Development using Life-cycle Performance Simulation*

⁵⁹ Ibid

⁶⁰ OREDA, *Offshore Reliability Data*. (2002)

⁶¹ www.oreda.com

⁶² OREDA, *Offshore Reliability Data*. (2002)

⁶³ www.oreda.com



According to Myers and Futchik, there is a pattern to the recurring mistakes and that these mistakes, in nearly every instance, can be avoided by modest expenditures. One of the factors mentioned contributing to less-than-optimal operating performance is the turnover of key personnel with reorganizations and downsizing reducing overall staff experience. Combined staffing, experience, and knowledge deficiencies have contributed to relying on outmoded technologies or inadequate familiarity with new technologies.⁶⁴

3.3 Plate heat exchangers – the product

Heat exchangers are used for the purpose of heat transfer. Heat transfer involves bringing two substances at different temperatures close to each other, so that one either heats or cools the other. This means that energy already in the system is simply transferred to another part of the process where it can be put to greatest effect. This will save money, energy and reduce the overall environmental impact of the production process compared to buying additional energy.⁶⁵

There are several types of heat exchangers, of which shell and tube heat exchangers and plate heat exchangers are two of the most widely known and used.

The basic PHE, shown in figure 8, consists of a series of thin corrugated metal plates that are gasketed and/or welded together. The plates are compressed together in a rigid frame to create an arrangement of parallel flow channels. One fluid travelling in the odd numbered channels, the other in the even. Further information on construction, is given in Appendix 2.⁶⁶ (Construction of a shell and tube heat exchanger is shown in Appendix 3).

⁶⁴ Myers, Merle H & Futchik, Dennis (2003): “Investors can minimize risk in upstream oil, gas projects”.

⁶⁵ *Alfa Laval – plate technology*. Alfa Laval. 2002.

⁶⁶ *Ibid.*



Figure 8 Plate heat exchanger

3.3.1 Reliability and failures of plate heat exchangers

Reliability was earlier defined as the “ability of an item to perform a required function under given conditions for a given time interval”⁶⁷ and the ability of an item to function without failures.⁶⁸ So what are the typical fault modes and failure causes for a PHE in general? What factors are affecting PHE reliability?

As mentioned earlier discussing and classifying failures and their causes is not easy as it is subject of human bias. However, for this survey we need some theory and classification of PHE failures. The most common fault modes and their causes and consequences will therefore be briefly described here.

Heat exchanger faults generally fall into one of two groups; mechanical faults or performance faults. Sometimes these two may be related.⁶⁹

A mechanical fault is usually external leakage or internal leakage. External leakage means that there is a leakage visible on the exterior of the PHE. External leakage failure causes can be:⁷⁰

⁶⁷ European Standard 13306:2001. *Maintenance Terminology*

⁶⁸ Bergman, Bo & Klefsjö, Bengt. (1991) *Kvalitet från behov till användning*

⁶⁹ *Heat Exchanger Service Guide*. Alfa Laval. 1998.

⁷⁰ Ibid

- ✓ Dislocation of gaskets, also called gasket blow-out, as a result of an abnormal increase in internal pressure.
- ✓ Damaged or crushed gaskets, which may be the result of overtightening of the plate pack, wrong re-assembly or unsuitable combination of process media and gasket material.
- ✓ Too low gasket force as a result of gasket wear-out or undertightening of plate pack.
- ✓ Damage of weld

An internal leakage means that there is mixing of the two substances, which generally indicates some form of hole or crack in one or several plates. There are many different causes of holes and cracks in plates, some are:⁷¹

- ✓ Corrosion by which the material is destroyed as a result of excessive local chemical attacks.
- ✓ Erosion, generally a localised mechanical wearing down caused by particles in areas with high media velocities.
- ✓ Fatigue which is caused by either
 - a) continuous pressure pulsations in the system or frequent start-ups/stops causing noticeable pressure variations, or
 - b) temperature fluctuations
- ✓ Damage of plates by foreign objects in the system or mistreatment when taking the unit apart.

Among the performance related faults gradual performance reduction due to fouling (also referred to as clogging) is a common fault.⁷²

For a PHE there are two types of basic fouling problems, fouling on the heat transfer area and plugging of the surface channels. It may put the heat exchanger in a degraded state with reduced thermal performance, pressure loss and restricted flow. Fouling can be the result of scaling, deposition of solids in the system or biological growth. A PHE can pass only a limited amount of solids and debris. If the size of particles exceeds the plate gap limitations, the inlet port area will be plugged. Process conditions highly influence the degree of fouling. Dirty media and low velocity of media are examples of factors that increase the tendency of fouling.⁷³ In most cases the PHE can still perform the required function in spite of the performance reduction.

When discussing failures of PHE it is worth mentioning that, in contrast to a turbine, compressor or pump, a PHE is a piece of static equipment i.e. it has no moving parts.

⁷¹ *Heat Exchanger Service Guide*. Alfa Laval. 1998.

⁷² Ibid

⁷³ Ibid

This means it cannot create pressure surges, energy, temperature changes, plugging solids or scale by itself.⁷⁴

In order for a PHE to be reliable it has to be designed properly for the application and process conditions in which it is to be used. Important design parameters are number, material and size of plates and choice of sealing i.e. gaskets or welds or a combination of the two. If gaskets are chosen the gasket material must be compatible with the media.⁷⁵

3.3.2 Operating instructions and preventive maintenance of plate heat exchangers⁷⁶

Following the operating instructions and practicing a suitable preventive maintenance will avoid many failures and ensure a longer operating life. With each PHE delivery Alfa Laval enclose one copy of the PHE instruction and maintenance manual. There is no space in this report to cover the whole subject of PHE operating instructions and maintenance. The most important issues for this survey will be summarized below:

Operating instructions

- ✓ Flush the system including the interconnecting piping of all foreign matter before initial start-up and after the system has been worked on.
- ✓ Avoid pressure variation and pressure shocks. Always open and close valves and pumps slowly. Operational changes must be made slowly and smoothly, use slow operating valves and pressure surge suppression devices if necessary.
- ✓ The PHE should be protected from large-solids. In high solids applications a filter/strainer should be used. Backflushing valves can also be used. It reverses the flow through the exchanger, as needed, to flush out any materials that may have accumulated in the inlet areas of the unit.
- ✓ Do not open the unit if not necessary. Dismantling and re-assembly of the PHE should be done under the direction of qualified field service personnel.

Maintenance instructions

Depending on the physical and chemical properties of the media and the thermal duty the PHE may need cleaning from every few months to never at all to ensure optimum heat transfer. The need for cleaning will show through a decrease in thermal performance and an increase in pressure drop across the unit and/or a reduction in the flow. When cleaning fouling build-up is removed. There are two methods available for cleaning the PHE:

- ✓ Opening the PHE and removing the plates from the unit for mechanical cleaning with a soft brush and high-pressure washing with water or a suitable cleaning agent. This cleaning can be done either on-site by qualified field

⁷⁴ Ibid

⁷⁵ Ibid.

⁷⁶ *Heat Exchanger Service Guide*. Alfa Laval. 1998.

service personnel or the PHE can be sent to a PHE service centre. This cleaning method tends to be very time-consuming and involves a risk of damaging the gaskets and plates, particularly if performed by untrained personnel. This type of cleaning cannot be used for welded units because the unit cannot be opened.

- ✓ Chemical cleaning of the plates without opening the unit. A chemical is then run through the unit dissolving and loosening any deposits. As long as the PHE is not plugged up completely with fouling build-up this can be a cost-effective solution by minimizing downtime and maintenance time.

Recommended spare parts are gaskets, plates with gaskets or full plate pack. Regarding replacement of parts the gaskets are the only part that normally requires replacement. The lifetime for gaskets varies from process to process and can range from 2 to 20 years. High temperature and high pressure shortens the gasket life. Planned regasketing of the PHE prior to gasket failure should be included in all maintenance programs for gasketed heat exchangers.

In case plates are damaged they should be replaced. There is no reliable way of repairing damaged plates.

3.4 The heat exchanger market - the competition⁷⁷

The global heat exchanger market is a large market spread out both geographically and on many different industries. The market as a whole is mature and slow growing. The competition is intense with many suppliers. Shell and tube heat exchangers are dominating the market with its traditional technology. The rest of the market is mostly constituted of plate heat exchangers.

The plate heat exchanger market grows above the industry wide average of heat exchangers of all types. Advantages that the newer plate technology has over shell and tube heat exchangers are:

- ✓ Compact size – often only about 20% of the size of the traditional installation
- ✓ More effective heat transfer – 3 to 5 times higher ratio
- ✓ Flexible design – the number of plates can be increased or reduced as the required capacity varies over time.
- ✓ Lower cost – both in terms of capital cost and installation cost

Although there are many benefits of choosing a PHE rather than a shell and tube, the technology conversion is moving quite slowly. The drawbacks of PHEs are technical limitations, which exclude them from use in very high temperature and pressure installations. Market drivers for shell and tube heat exchangers are versatility and familiarity; everyone knows the technology and how to handle the equipment.

⁷⁷ The information in this section comes from various sources within Alfa Laval

There are also expenses involved in a technology conversion. The plants and platforms are planned to suit the shell and tubes so adjustments might be needed if changing to PHEs. Maintenance routines and operating instructions are not the same for shell and tubes and PHEs. Therefore a technology conversion requires new knowledge and a change in behavior of the operators.

Alfa Laval has estimated that the market for PHEs in the oil and gas industry is far from saturated and sees a growth potential and therefore an opportunity in increasing their market share.

3.5 Related research findings

The findings of related research are of use both in designing the research and to gain an understanding of the current state of knowledge in the subject. This research project is rather specific and relevant previous research have therefore been difficult to find. A few interesting findings have been found and these are presented separately in sections 3.5.1-3.5.3

3.5.1 OREDA⁷⁸

In section 3.2.1 the OREDA (Offshore Reliability Data) project was introduced. The project organization consists of eight major oil companies and the contractor, SINTEF. The idea of the OREDA project, which started in the early 1980's, was to survey the reliability of important offshore equipment under real life operational conditions, by collecting reliability field data and merge into a reliability database.

In the beginning of the project, OREDA data was primarily needed for risk and availability studies in the early concept phases of an offshore field development. However, there has been an increasing interest in data for use in maintenance optimization.

The collection of data has been carried out in several phases with some variation of focus and equipment classes included. The choice of equipment on which the data was to be collected was selected by the oil companies and was mostly topsides equipment. Heat exchangers have been included as an equipment class in all phases of the project.

OREDA handbooks have been published to present the data collected for the different types of equipment classes. The data presented are failure modes, estimated failure rates and repair time. The latest handbook, published in 2002, covers the data collected in 1993-2000. Data for 68 heat exchangers at 12 platforms was collected during this time. Table 1 shows a summary of failure rates, based on calendar time, for these units. Failure rates are given in number of failures per 10^6 hours.

⁷⁸ All information in this section comes from *OREDA, Offshore Reliability Data*. (2002) and www.oreda.com

No of failures	Failure rate (multi sample)			Failure rate (homogenous sample)
	Lower	Mean	Upper	n / τ
212	19,89	88,98	198,74	100,58

Table 1 Summary of heat exchanger reliability data collected by OREDA

Out of the 68 heat exchangers, 14 are PHEs, whereas almost all of the others are shell and tube. See table 2 for a summary of the reliability data, based on calendar time, for the 14 PHEs (collected from 4 platforms).

No of failures	Failure rate (multi sample)			Failure rate (homogenous sample)
	Lower	Mean	Upper	n / τ
32	5,50	71,15	201,72	66,35

Table 2 Summary of plate heat exchanger reliability data collected by OREDA

Comparing estimated failure rates for heat exchangers with failure rates of rotating machinery equipment shows that heat exchangers have significantly lower failure rates. As an example compressors have a mean estimated failure rate of 656,86 failures/ 10^6 hours and gas turbines 1199,23 failures/ 10^6 hours.

Some of the topsides equipment have lower estimated failure rates than heat exchangers, for example valves with a mean failure rate of 31,05.

In order to be able to compare the reliability data collected in different projects it is necessary to know the definitions and conditions of the research. It is most often difficult to find out all this information. Some of the conditions for collected data in the OREDA project are given below:

Data collected are in general not covering the whole lifetime of equipment, but 2-4 years of operation. The main part of the failure events comes from the useful life phase. The failure rate estimates are therefore based on the assumption of a constant failure rate. Failure is defined as "the termination or degradation of the ability of an item to perform its required function(s). It includes:

- ✓ *Complete failure of item*
- ✓ *Failure of part of the item that causes unavailability of the item for corrective action*
- ✓ *Failure discovered during inspection, testing, or preventive maintenance that requires repair*
- ✓ *Failure on safety devices or control/monitoring devices that necessitates shutdown, or reduction of the items capability below specified limits."*

3.5.2 Operational experiences for heat exchangers at oil platforms⁷⁹

In 1988 SINTEF carried out a specific survey of operational experience for heat exchangers at oil platforms on the Norwegian Continental Shelf (NCS). The objective of the project was to collect and analyse operational and maintenance data. Identification of failures and problem areas was given special attention.

Four oil companies, with a total of 355 heat exchangers, participated in the survey. Out of the surveyed units 77,2% were shell and tube heat exchangers, 8,5% plate heat exchangers, 3,9% air coolers and the rest was unknown.

The survey is based on verbal and written information received from contact persons in the oil companies. It was noticed that maintenance personnel is a very valuable source of information, since they are concerned with the equipment on a daily basis.

The most serious problems noticed for the different types of heat exchangers were the following:

- ✓ Shell and tube – Galvanic and pitting corrosion causing leaks in tubes, tube sheets, connections, channels and plugs.
- ✓ Plate heat exchangers – Leaks in gaskets, may be due to the ageing of gaskets.
- ✓ Air coolers – Too high cooling efficiency when outside temperatures get too low or when wind chill is strong.
- ✓ Fouling and deposits were a problem for all heat exchanger types.

None of the companies have reported any accidents or hazardous incidents connected to the heat exchangers.

3.5.3 Reliability of plate heat exchangers in the power industry⁸⁰

A reliability customer survey of the Alfa Laval plate heat exchangers delivered to power plants was carried out by Alfa Laval in 1982-1985. The data collection method was self-administered questionnaires distributed by mail. The collected data covered 474 units in 18 countries. The units in this survey were utility heat exchangers and not process heat exchangers as in the oil and gas survey. Utility heat exchangers generally have lower temperatures, lower pressure and less aggressive media. Interesting findings and observations from the survey are:

- ✓ Only 35 failures were reported and the failure rate was found to be around 2 failures per million operating hours.
- ✓ In case users did have problems with their PHE, these were often initial technical problems during installation and start-up.

⁷⁹ Bonå, Lars Erik et al. (1988) *Survey of operational experience for heat exchangers/coolers*.

⁸⁰ *Reliability of plate heat exchangers in the power industry*. Alfa Laval.1987.

- ✓ The most common fault mode reported in the survey was external leakage caused by gasket failure. However it was not possible to divide all failures into the fault modes.

The researchers also noticed that it was difficult to distinguish between preventive and corrective maintenance based upon the descriptions reported in the survey. For example maintenance to remedy fouling after many years in operation was regarded as a failure if reported as a failure, even though it could have been avoided by preventive maintenance.

4 METHOD

In this chapter the research method is discussed and described. First the general basis for choice of method is presented. Next the survey procedure is described. Finally the reliability and validity of the research is discussed.

4.1 Choice of method

The problem and purpose was the starting point for the choice of method and the design of the survey. The method chosen is the one expected to fulfil the purpose in the best way. The detailed design of the survey is a result of three interrelated dimensions: the project framework, choice of approach and type of data. The relationship is presented in figure 9.⁸¹

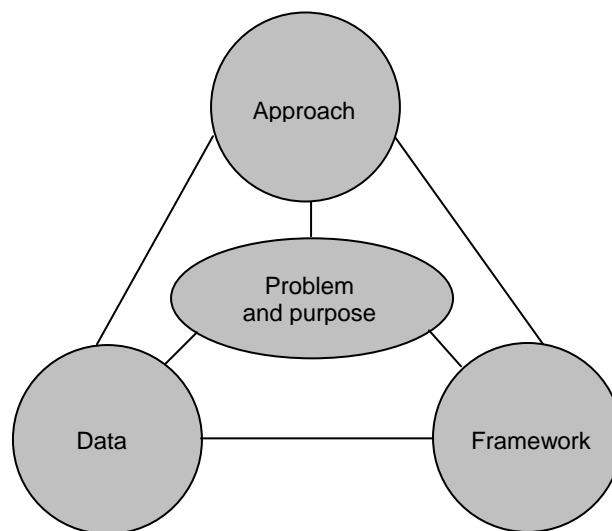


Figure 9 Choice of method

Chapter 2, the theoretical framework and chapter 3, the survey environment, together form the project framework, providing important concepts and information relevant to the problem. The framework is used in understanding the problem, purpose and environment of the research. It decides from what perspective the problem is looked upon and how it is handled. Interviews and desk-research provided the information for this particular framework.⁸²

The approach of a research study determines the type of study and what type of results that can be obtained from it. The approach that was chosen to best suit the criteria of this study was a cross-sectional survey. This is an advantageous approach

⁸¹ Christensen, Lars et al (2001) *Marknadsundersökning – en handbok*.

⁸² Ibid

when the study has a descriptive purpose and this description is to be quantified. It gives the opportunity to gather a large amount of data from a sizeable population, which is of interest in this case. The survey approach is also perceived as authoritative by people in general because it is easily understood.⁸³ A drawback of the approach is the lack of information depth in individual cases. Also, the data collected by this method may not be as wide ranging because there is a limit to the number of questions to be posed.⁸⁴

The chosen cross-sectional survey approach focuses on quantitative primary data, which makes it possible to make statistical generalizations. This type of data is needed in order to answer the research questions stated. However, this does not mean that the survey will not include any qualitative data at all. These two types of data cannot be seen as independent of each other, both are needed to describe the reality in which our research takes place.⁸⁵

To summarize the method chosen, it is a cross-sectional survey focusing on quantitative primary data.

4.2 Survey procedure

As the overarching choice of method was determined the survey procedure could continue. (Figure 10 displays the activities in this procedure.) Identification of the target population and the creation of a frame, a list of target population members, was the next step. After that the difficult task of finding respondents took over. As respondents were found one after another the data collection started. The activities of finding respondents and collecting data were running simultaneously. Finally all collected data needed to be coded and interpreted in order to present any results and make conclusions.

The activities in the survey procedure will be described in more detail in the following sections, 4.3 – 4.6.

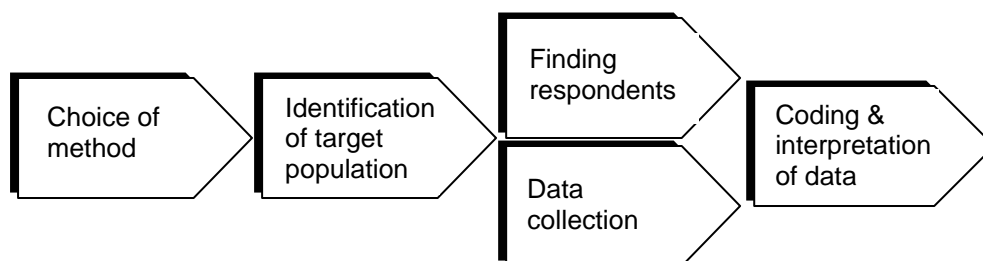


Figure 10 Activities in the survey procedure

⁸³ Saunders, Mark, Lewis, Philip & Thornhill, Adrian. (1997) *Research Methods for Business Students*.

⁸⁴ Christensen, Lars et al (2001) *Marknadsundersökning – en handbok*.

⁸⁵ Ibid

4.3 Target population and frame

The target population, i.e. the population I wanted information about, in this survey was defined as all process PHEs delivered by Alfa Laval to production platforms in the offshore industry and have been in operation for at least 6 months.

These PHEs are installed at more than 200 offshore platforms worldwide. Some of the platforms have several installations whereas others only have one. Each installation consists of one or several PHE units. The survey elements of this survey will be installations.

In order to carry out a survey, a list of target population members, a so-called frame, was needed. To obtain an appropriate list is difficult in most cases, as lists of specialized populations usually do not exist. In this case the Oil & Gas installation database, mentioned in chapter 3.1, have been the major source for creating a list. The database covers at least 90% of the target population.⁸⁶

A list of installations that belong to the target population was created from the database together with the information from local Alfa Laval employees. The list created is estimated to cover about 90% of the total target population.

The size of the frame, the list created from the database, is 593 installations, which includes 1048 units. The size of the target population was then estimated to lie in the range of 650 - 750 installations.

The intention was to carry out a census survey, i.e. collecting data from all population members in the frame in order to gather as much reliability data as possible.

4.4 Finding respondents

In order to collect the data, respondents were to be identified and located. One respondent at each platform was required. The criteria for the respondents were; a person who deals with the PHEs in his/hers daily works and has a good knowledge of the performance and operation of the units. This would typically be a process engineer or maintenance personnel working for the end-user company, usually an oil and gas company.

As described in chapter 3.1.2 these persons, the end users, are the last links in the customer chain and, in most cases, not involved in the purchasing of the equipment. Moreover there seems to be a fairly high rate of staff turnover in these positions. For these reasons the identification of respondents became a time-consuming and difficult procedure.

The methods for finding the respondents were several. The knowledge and support of regional sales representatives and service engineers within Alfa Laval was a key factor in succeeding. They were informed about the survey and asked to give contact information to platforms such as an e-mail address or phone number. Getting access

⁸⁶ Tobias Svensson, Alfa Laval Oil & Gas Technology

to many of the platforms was relying on the support of these persons. In some cases this support was difficult to get due to their lack of information or time constraints.

Other ways to find respondents were also tried, such as calling the oil company directly and ask for a number to a specific platform. In some cases this worked but then required numerous phone calls.

Usually it was necessary to talk to several persons at a platform before finding someone fulfilling the respondent criteria.

As the project proceeded it turned out that the problem of getting access to platforms and respondents had been underestimated. Because the sales process typically involves many parties and because Alfa Laval often does not sell directly to the end user it is very difficult to track delivered items to the end user if not in the database or if information on location is missing. Even if the end user company is known the chances to locate the plate heat exchangers are small. Most oil companies have a large number of facilities spread out geographically with not much contact between each other.

The access problem consisted of two specific problems; 1) It was not possible to locate all installations to a specific platform. 2) It was not possible to find respondents at all platforms and for some regions.

4.5 Data collection process

Choosing data collection method for a survey in an international context needs further considerations when choosing method than domestic or local surveys. For example are personal interviews not a feasible solution. Telephone interviews is a possible solution but some of the wanted information in this case is of such character that the respondent may have to do some research to answer the questions, for example from maintenance records.

The technique chosen for collecting primary data was therefore using self-administered questionnaires distributed by e-mail. Because each respondent is asked the same set of questions, this technique provides an efficient way of collecting responses from a large number of installations prior to quantitative analysis. Disadvantages of this technique are that it sometimes has serious non-response problems. Distributing the questionnaires by e-mail was considered to be faster and yield a higher response rate than regular mail.⁸⁷

4.5.1 Designing the questionnaire

The design of the questionnaire was the result of collaboration between the researcher and employees at Alfa Laval from the departments Oil & Gas Technology and Parts & Service. The questionnaire and results from the previous Alfa Laval reliability survey, for plate heat exchangers in the power industry (section 3.5.3) was helpful in this work.

⁸⁷ Saunders, Mark, Lewis, Philip & Thornhill, Adrian. (1997) *Research Methods for Business Students*.

Designing individual questions involves the choice of open or closed questions or a combination of the two. Open questions allow respondents to give answers in their own way. Closed questions provide a number of alternative answers from which the respondent is instructed to choose. For this survey most questions were designed as closed questions because they are usually quicker and easier to answer. Responses are also easier to compare.⁸⁸

Effort was put in to making the order and flow of questions logical to the respondent. The design of the questionnaire layout was focused on making reading questions and filling in responses easy.

The questionnaire distributed to respondents in US was modified to be shorter. The reason for this was that contact persons for the survey within Alfa Laval in US considered the questionnaire to be too long and needed to be shortened. Some of the less important questions were then eliminated. Replacing several closed questions with one open question also shortened the questionnaire.

See both questionnaires in Appendices 4 and 5.

4.5.2 Distributing and collecting questionnaires

As respondents were identified they were contacted by phone for a so-called pre-survey contact. They were informed of the survey and asked to participate. This was both a way of getting the correct e-mail address and a way of increasing the response rate.

Usually respondents were difficult to reach by phone. A lot of time was therefore spent on calling respondents who did not answer the phone. Very few of the persons that were asked to participate denied the request although many said they were busy and may not get the time to respond. With the permission of the respondent questionnaire/s were sent by e-mail accompanied by a covering letter. The covering letter explained the purpose of the survey and instructions on how to fill in the questionnaire.

In some cases the respondent preferred giving the response by phone, whereby the questionnaire was filled in by the researcher according to the respondents answers to the questions. The benefit of responses by phone was that the respondent was able to ask if he/she did not understand a question. It was also possible to ask further questions, which decrease the risk of misinterpreting the questions.

The questionnaire was created as a form in MS Word in order to simplifying filling in the responses and increase the response rate. It made it possible for the respondent to write the answers directly on the computer and return the questionnaire by e-mail.

In order to increase the response rate and receive as much data as possible reminders were e-mailed to the respondents not answering within a few weeks. A second reminder was e-mailed after another few weeks if no reply was received. If there was still no reply after the second reminder the respondent was tried to be reached by

⁸⁸ Ibid.

phone in order to ask if he/she would be able to give a reply at all. All responses were followed up by an e-mail to thank the respondent for their time and effort.

The biggest problem in distributing and collecting the questionnaires was the difficulty in reaching the respondents. Other factors complicating the communication in some cases were time differences to some regions and language difficulties.

Respondents were reached for a total of 402 installations. Questionnaires were distributed to all of these. The total data collection procedure took place between October 2002 and September 2003.

4.6 Coding and interpretation of data

In order to present any results and be able to draw any conclusions from collected data it needed to be coded and interpreted. All questionnaires were read carefully and data were recorded in a database. When all the data were recorded, statistical analysis and estimation of failure rate were carried out. The results of this will be presented in the next chapter.

Some specific issues involved in the interpretation of data and estimation procedures will be covered in the following sections, 4.6.1 – 4.6.4.

4.6.1 What is considered as a failure?

What should be considered a failure? It was mentioned in section 3.3.1 that reported failures is nearly always subject to human bias and emotion and that wholly objective failure data is very rare.

However, in this particular survey the interest is on the end users perception on the reliability of Alfa Laval plate heat exchangers and subjective data is therefore not a problem. The failures reported are events that the respondents i.e. the end users of the product consider to be failures. Because of this a similar event may be reported as a failure in one case but not in another.

As for the component boundary definition, only failures on the heat exchanger itself and its parts are included in the survey (although these can be due to failures of other equipment). No valves, piping or control and monitoring devices are thus included in the component boundary definition.

4.6.2 Calendar time or operational time?

As mentioned in section 2.3.2 aggregated time in service may be presented as either calendar time or operational time.

Calendar time was chosen to present the aggregated time in service for installations in this survey. The reason for this choice is that most units are in continuous operation and do not spend much time in maintenance, which makes calendar time close to the operational time. Also, data regarding maintenance and repair times is very difficult to obtain. Calendar time is therefore less uncertain than operating time would be.

Aggregated time in service have been calculated for all units in the installations in continuous operation by counting 6 months of the start-up year and after that, whole years until 2003 or, if not in service anymore, the year they were taken out of service. Stand-by units and back-up installations have not been included in the aggregated service times.

4.6.3 Assumption of a constant failure rate

The estimation of an average failure rate value requires the assumption of a constant failure rate, i.e. that data comes from the useful life phase of the installations (described in chapter 2.3). In the majority of cases this is true for the collected data in this survey although there are also failures from the burn-in phase included. It is difficult to tell the degree of this since the definition of a burn-in phase for a heat exchanger is somewhat unclear. Data from the wear-out phase is not included. Equipment is generally taken out of service before reaching this phase.

4.6.4 Homogenous sample or multi-sample?

The installations in our sample have *individual* variations not only in location but also in process conditions, operating conditions, age, PHE type and maintenance routines. This means that the sample is homogenous in the way that all sample elements are different from each other.⁸⁹

A homogenous sample means that all the items included are the same type of item operating under the same conditions. In this case “same” means that they are all different from each other. To use the multi-sample procedure for estimating failure rates we need to know of a variation between sub-samples within the larger sample.

A test of variation between individual sample elements resulted in the value 0, i.e. no variation between samples. The below formula for homogenous samples were therefore used in estimating the failure rate. The χ^2 distribution was used for estimating the confidence limits on the failure rate estimate.

Failure rate estimate formula used:

$$\lambda = \text{Number of failures} / \text{Aggregated time in service} = n / \tau$$

With n failures during an aggregated time in service τ , the 90% confidence interval is given by:

$$(1 / 2\tau * z_{0.95, 2n}, 1/2\tau * z_{0.05, 2(n+1)})$$

where $z_{0.95, v}$ and $z_{0.05, v}$ denote the upper respectively lower confidence limits of the χ^2 distribution with v degrees of freedom.

4.7 Reliability and validity

The credibility of research findings rests upon the achievement of reliability and validity. The assessment of reliability is about answering the question: *Will the measure*

⁸⁹ Anna Lindgren, Department of Mathematical statistics, Lund Institute of Technology

yield the same results on different occasions (using the same method)? Validity is concerned with whether the findings are really about what they appear to be: *Did we measure the things we wanted to measure and is the measured value close to the real value?*⁹⁰

There is bound to be a number of errors when surveys are conducted, some of which can be controlled and others of which cannot be controlled, affecting reliability and validity.⁹¹ The choice of method always involves a trade-off between a number of pros and cons in different ways to design the research. Moreover resources are limited, both in terms of time and money, when conducting a survey, also increasing the risk of error.⁹²

A documentation of possible sources of error, affecting the reliability and validity, will increase the credibility and usefulness of the survey.⁹³

Sources of error can come from all parts of the research project such as identification of the research population, data collection, data interpretation and development of conclusions. The implications of possible sources of error relevant for this particular survey will be discussed below.⁹⁴

4.7.1 Research population and target population

In section 4.2, the target population and the frame, list of installations belonging to the target population, was discussed. It was not possible to identify all members of the target population. The list created is estimated to cover about 90% of the total target population. This means that we have a slight subset problem; the frame is smaller than the target population. If these 10% would be systematically different from the rest of the population there is a risk for biases in the results.⁹⁵ However, no such systematic differences are known. Moreover it is a fairly small error, subset and superset problems sometimes account for as much as 30-40% of the frame.⁹⁶ The frame created represents the target population well.

Getting access to and identifying respondents was a problem mentioned in section 4.3. Respondents were found for 68% of the installations in the frame. There is nothing in common for *all* of the installations, for which no respondents are found. However, many of them are installations in South America and Middle East where it was more difficult locating and finding respondents. The reason for this was lack of support from local Alfa Laval offices combined with language difficulties. If installations in these regions are systematically different from installations in other regions there is a risk for biases. Any such differences are not known of.

A disadvantage of using self-administered questionnaires for primary data collection, which was earlier mentioned, is the non-response problem. A high response rate is

⁹⁰ Saunders, Mark, Lewis, Philip & Thornhill, Adrian. (1997) *Research Methods for Business Students*

⁹¹ Kumar, V, Aaker, David & Day, George. (1999) *Essentials of marketing research*.

⁹² Christensen, Lars et al (2001) *Marknadsundersökning – en handbok*

⁹³ Ibid

⁹⁴ Saunders, Mark, Lewis, Philip & Thornhill, Adrian. (1997) *Research Methods for Business Students*

⁹⁵ Ibid

⁹⁶ Lekvall, Per & Wahlbin, Clas. (1993) *Information för marknadsföringsbeslut*.

important to ensure that the research population is representative for the target population. There were several measures taken in order to increase response rate in this survey. These are described in chapter 4.4. and include ensuring good questionnaire design, e-mail distribution and collection, pre-survey contact and reminders. The reminders took a lot of time but showed to have a significant impact on the response rate.⁹⁷

Out of the 402 questionnaires that were distributed, 213 responses were received, yielding a response rate of 53%. However, 39 responses were invalid with important information missing. This result in 174 valid responses. The reasons for non-responses are usually not known but many respondents have given lack of time as an explanation.

The three sources of error discussed above all are concerned with the researched population being representative for the target population. A representative sample is one that exactly represents the population from which it is taken.⁹⁸ Although there is a risk of bias due to the possible sources of error discussed above I consider the researched population in this survey to be representative for the target population in terms of processes conditions and environments.

4.7.2 Data collection

Using self-administered questionnaires there is always a risk of respondents misinterpreting questions or not answering specific questions. This may be a source of error affecting the results.

Any subject bias i.e. respondents answering what they think is the right answer may be a risk but is not likely to have occurred. Respondents would not have any interest in that or gain anything from it.

The most likely source of error in the data collection is the risk of failures and corrective maintenance actions not being reported because they are unknown to the respondents. The extensive turnover of personnel and lack of keeping adequate maintenance records, especially historically, contribute to this risk. This risk will possibly lead to a lower average estimated failure rate than the true value and higher failure rates for more recent installations.

4.7.3 Data interpretation and results

When coding the collected data there is a risk of mistakes due to human error or subjective interpretation. This has been prevented through careful documentation and keeping an objective point of view.

The interpretation of data and results will depend to a large extent on the theoretical framework used and the assumptions made. Effort has been put into finding relevant and reliable sources to achieve an awareness of the current state of knowledge in the research subject and form a suitable framework.

⁹⁷ Saunders, Mark, Lewis, Philip & Thornhill, Adrian. (1997) *Research Methods for Business Students*

⁹⁸ Ibid.

The estimation procedures used and the assumptions made are described in section 4.5.

4.7.4 Development of conclusions

The final source of error comes from the risk of developing incorrect conclusions by making a logic leap. This risk will increase if the data collected is insufficient. The conclusions drawn in this report is based upon the findings from the survey and not far-reaching. The ambition is to answer the research questions and to hold up what is interesting and useful for Alfa Laval. Other conclusions from the results are left to the reader to make.

5 SURVEY RESULTS

The purpose of this chapter is to present results from the survey in an objective and meaningful manner. The chapter begins with a description of the characteristics of the surveyed units. After that the results of the survey regarding reliability, failures, maintenance and other observations will be presented.

5.1 Characteristics of surveyed installations

A total of 174 installations including 309 units at 60 platforms in nine countries were surveyed. (UK, USA, Norway, Denmark, Australia, Equatorial Guinea, Brazil, China and the Netherlands)

The time since start-up for the surveyed installations varies between 9 months and 25 years. The estimated aggregated time in service for all units is 1933 years, corresponding to nearly 17 million hours ($16,933 \cdot 10^6$ h). The estimated mean number of years in service for one installation is 6,3 years. The mean useful life of a PHE is not possible to calculate from the information gathered in this study because 95% of the installations are still in operation. However, 16% of the units have been in operation for 10 years or longer at the time of the survey.

The units are operating in topsides production, in processes such as crude oil dehydration, secondary cooling and gas compression. Figure 11 shows the distribution between processes for surveyed installations.

67 % of the installations have gasketed units, 24 % have semi-welded units and 9 % have fully welded units.

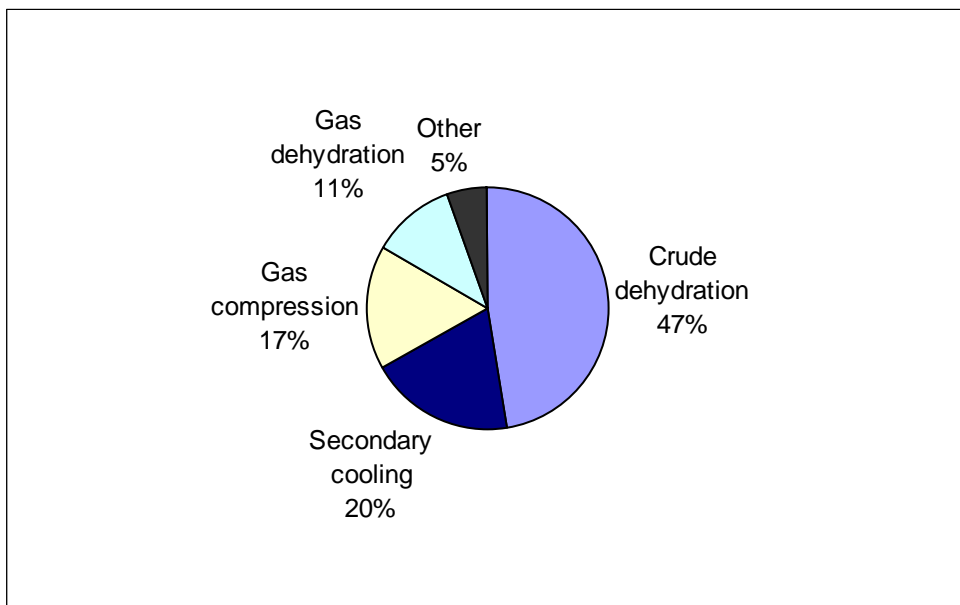


Figure 11 This is the distribution of processes that the surveyed plate heat exchangers are installed in

5.2 Failure data

5.2.1 Occurrence of failure and estimation of failure rate

A total of 104 failures were reported for the 174 installations. For a majority of the installations no failures were reported. The distribution of failures is shown in figure 12.

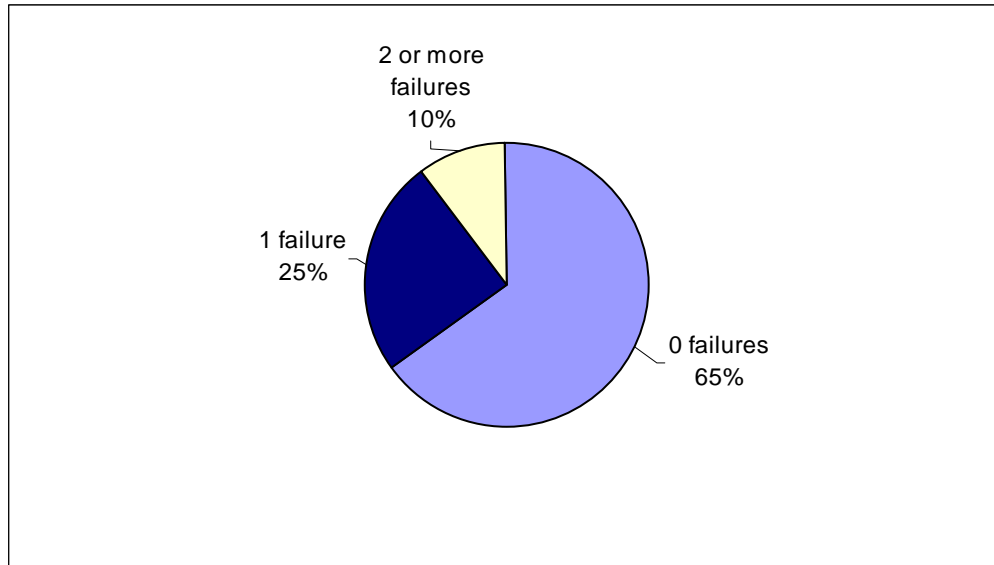


Figure 12 Distribution of reported failures on surveyed installations

The installations with no reported failures, 65%, naturally has an estimated failure rate of 0 failures per million operating hours. Failure rates for the rest of the installations vary between 0 and 150 failures per million hours, with 93% under 60 failures/ 10^6 h. The individual failure rates are presented in figure 13.

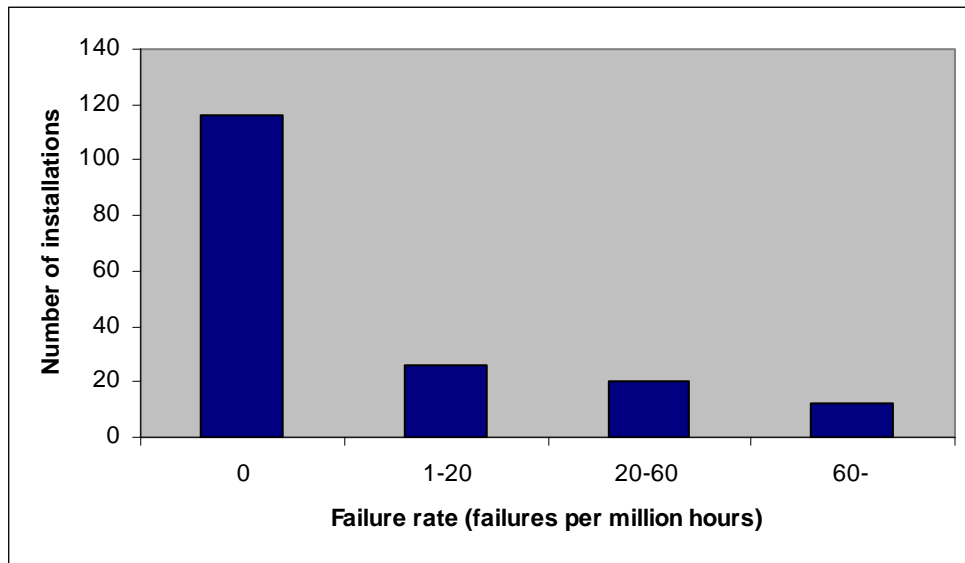


Figure 13 Individual failure rates for surveyed installations

Assuming a constant failure rate the estimated average failure rate based on reported failures is given by:

$$\hat{\lambda} = n / \tau = 104 \text{ failures} / 16,933 * 10^6 \text{ h} = \mathbf{6,14 \text{ failures} / 10^6 \text{ h}}$$

A 90% confidence interval is given by

$$\begin{aligned} & (1 / 2\tau * z_{0,95, 2n}, 1 / 2\tau * z_{0,05, 2(n+1)}) = \\ & = (1 / 33,866 * 10^6 * 175,6263, 1 / 33,866 * 10^6 * 244,8076) = \\ & = \mathbf{(5,19 \text{ failures} / 10^6 \text{ h}, 7,23 \text{ failures} / 10^6 \text{ h})} \end{aligned}$$

In figure 14 the estimated failure rate for individual installations is plotted against the age of the installations. Note that a majority of the “dots” are on the x-axis corresponding to an estimated failure rate of 0. It is obvious that the average of estimated individual failure rates do not correspond to a constant average failure rate. It can be seen that estimated failure rates drop significantly for installations older than 10 years. The reason for this will be discussed in the chapter 6.

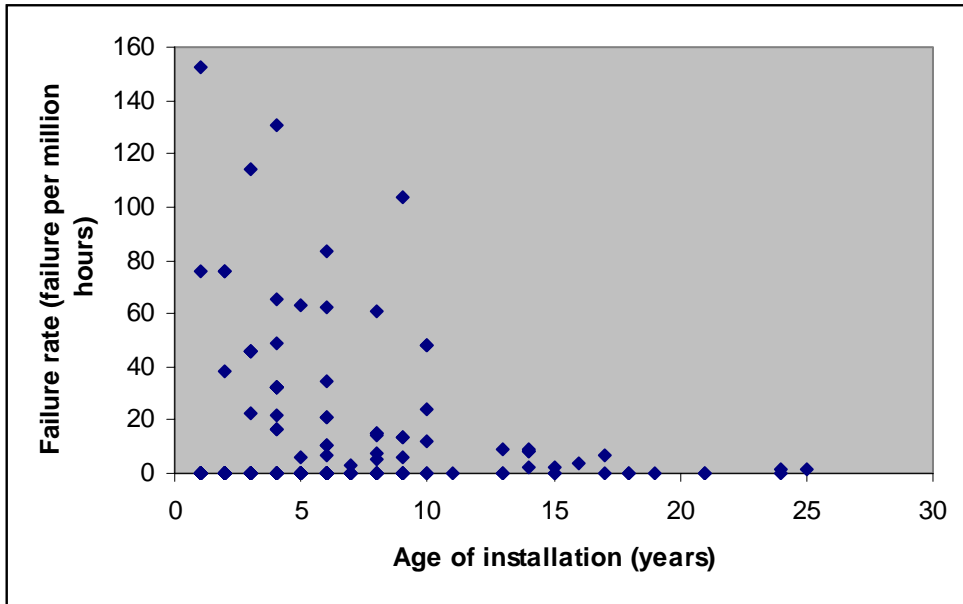


Figure 14 Individual failure rates vs age of installation

5.2.2 Fault modes

The most common fault mode reported was external leakage with 45% of the reported failures. Second was unexpected performance including reduced thermal performance and reduced flow. Figure 15 shows the distribution of the reported fault modes.

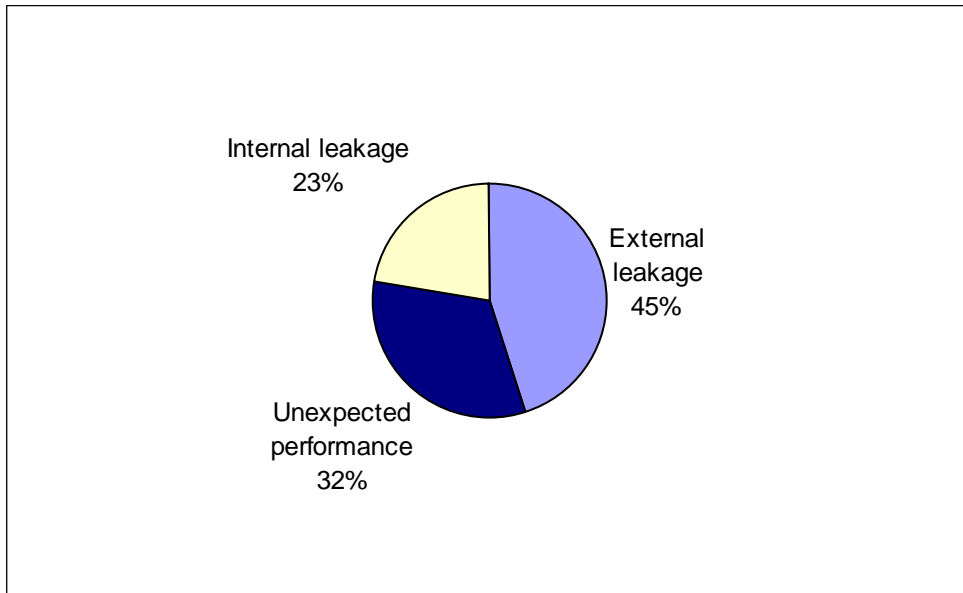


Figure 15 Fault modes reported in survey

5.2.3 Failure cause

Distribution of failure causes is presented in figure 16. The most common failure cause is fouling causing reduced thermal performance and restricted flow. Common types of fouling reported include scaling, deposition of solids in the system and biological growth.

The reported fouling problems are generally divided into two groups of installations. The first and larger group includes units that have been in service for many years which eventually need cleaning and after cleaning have no more fouling problems for many years again. In the other group are installations, which seem more prone to fouling and report recurring failures due to serious fouling problems. In some cases reasons for these problems have been given. One example is dirty media and no filter. Another one is severe biological growth.

Gasket blow-out and gasket wear-out is typical causes of external leakage. Reasons for gasket blow-out were not always reported, although overpressurisation of system and pressure spikes often were mentioned. Looking at the time frame, gasket wear-out is often due to the ageing of gaskets that have not been replaced. However, in some cases gasket wear-out is reported after only one year in service.

The failure causes included in “Other” include different types of damage to the plates where the reason was unknown to the respondent. Many times the failure cause was not known at all by the respondent.

Reported causes of internal leakage are fatigue, erosion, corrosion, damage of plates and gasket failures.

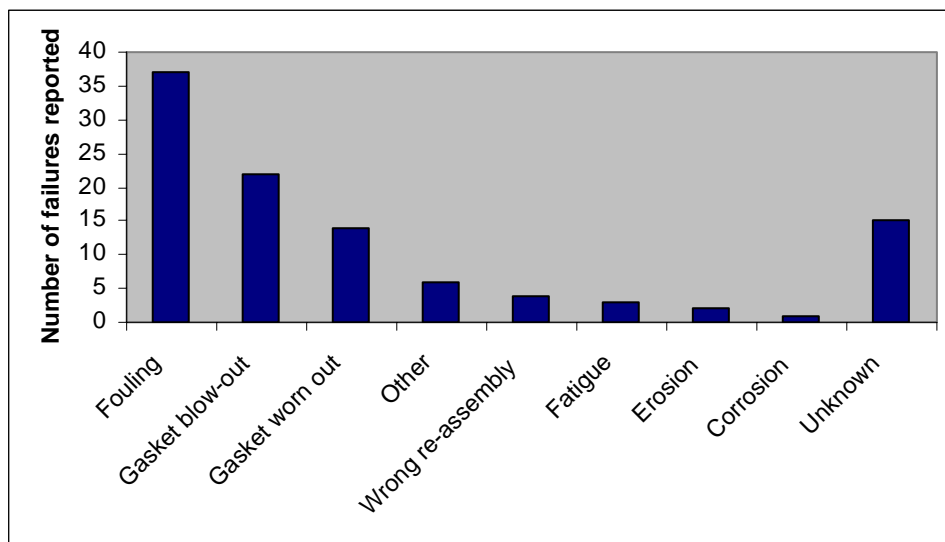


Figure 16 Failure causes

5.2.4 Corrective maintenance - repair

Corrective maintenance after fault recognition usually involves the replacement of plates or gaskets and/or cleaning. See distribution of corrective maintenance actions in figure 17.

The replacement of plates can be replacement of a few plates as well as all the full plate pack. Note that replacement of plates includes the replacement of gaskets, since gaskets are attached to the plates. The cleaning carried out as corrective maintenance is in a majority of the cases manual cleaning.

The corrective maintenance carried out after the recognition of an external leakage is an even distribution between replacement of gaskets and the replacement of plates. In general the corrective action reported for internal leakage is replacement of plates although replacement of gaskets is also reported in several cases. As for unexpected performance, cleaning and sometimes replacement of plates are the reported corrective maintenance actions.

In a few cases the PHE was taken out of service after failure. The reason for this was either that the service was not needed on the platform anymore or that a new PHE unit replaced the old one. "Other" means a minor correction like retightening of bolts or balancing differential pressure.

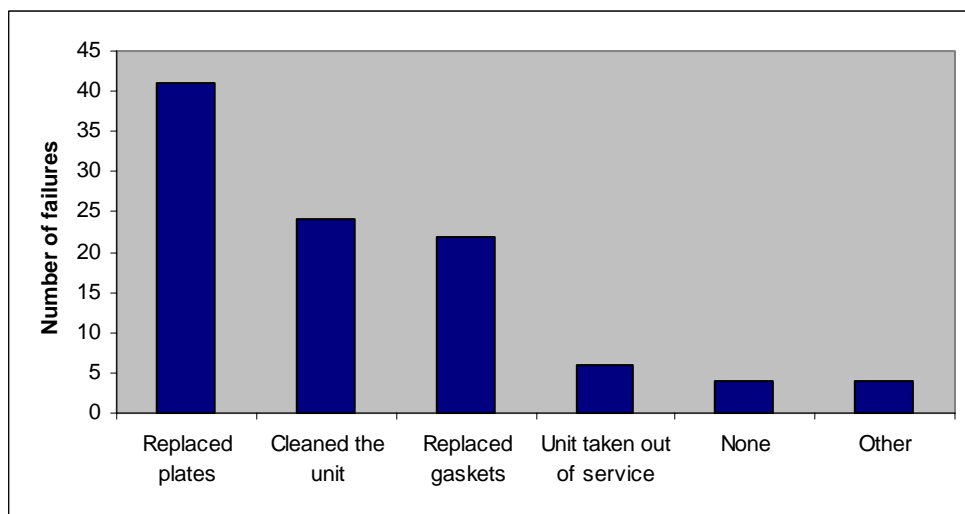


Figure 17 Corrective maintenance actions

5.2.5 Failure influence on production process

A majority of the failures were detected during normal operation. The distribution of the reported failures' influence on the process is presented in figure 18. In 56% of the cases, failures did not have any influence on the production process at the platform, for 28% a reduced capacity was noticed and for 16% a process shutdown was required.

External leakages caused in 63% of the cases *no influence on process*, in 20% *reduced capacity* and in 17% a *shutdown*.

Internal leakages caused *no influence on process* respectively *shutdown* in 38% each of the cases. For the rest of the cases, 24% *reduced process capacity* was reported.

Unexpected performance faults caused a *reduced process capacity* in half the cases and had *no influence on the process* in the other half.

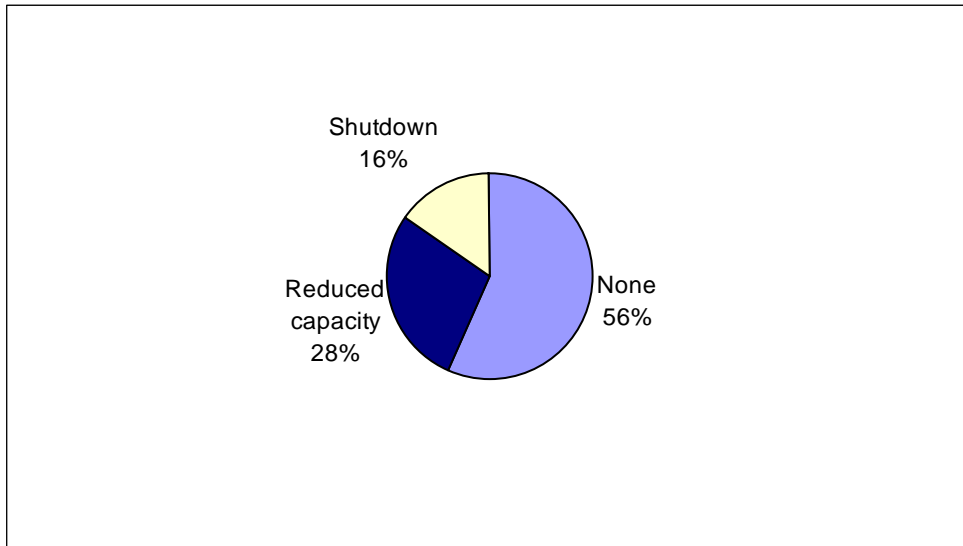


Figure 18 Distribution of failure influence on process

5.3 Preventive maintenance

The questions regarding preventive maintenance differed between the original questionnaire and the modified questionnaire used for US installations. The results for US installations, regarding this issue, will therefore be presented separately in section 5.3.5.

First some general comments from respondents regarding the maintenance of the plate heat exchangers are presented:

“I know that we have opened and cleaned the cold side at least once (removed shell and mussels) but generally there is little or no need for cleaning the plates. If and when this becomes necessary we replace the pack and return the old plates to Alfa Laval for service.”

“The exchangers have been very reliable. The only significant maintenance done is chemical cleaning. This is done on the seawater side by taking the cooler off line for two hours to remove any scale build up. This has been carried out twice since establishing the procedure last year. This allows us to maintain the cooler performance.”

“Spare plate packs are kept for replacement typically every 4 years. Old plates are taken onshore, gasket is removed, plates are cleaned and new gaskets glued on by Alfa Laval. Time to do this job is

unknown. Waxing is controlled by turning off the cooling medium (seawater) typically twice per week, for 45 minutes or so.”

“Maintenance routine is monthly hot flush and annual inspection (not carried out for the past two years due to the adequate performance).”

“Oil production rate has declined over the years therefore has reduced capacity on exchanger not affected the platform capacity until now. The reason for not cleaning or maintenance is therefore low accessibility or low prioritising.”

“The main operating problem during the past two years has been that scale has been deposited on the plates on the process side of the crude oil coolers causing increased differential pressure and reduced suction pressure and cavitation in the downstream export oil booster pumps. The interval of chemical cleaning has been up to 2-3 times a year per cooler. After start-up of scale inhibitor dosage in the upstream process, this problem has almost disappeared.”

5.3.1 Inspection

The first question regarding preventive maintenance was: *Has it been required to open the unit for inspection?* Responses to the question are presented in figure 19. Almost half, 48%, of the installed units were reported to never be opened for inspection. The ones that were opened were in general the units that currently or earlier had problems. One respondent wrote: *“The units are never routinely inspected, only on observation of poor performance.”*

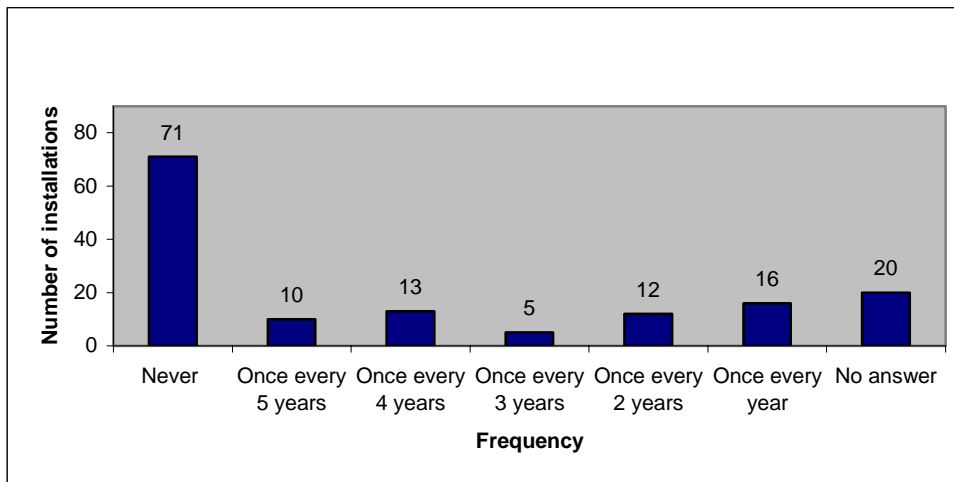


Figure 19 Frequency of opening unit for inspection

5.3.2 Manual cleaning

The questions regarding manual cleaning showed the same tendency as the previous question. Half (51%) of the installations were never manually cleaned. The frequency of cleaning varied between the remaining installations. Figure 20 shows reported cleaning frequencies. The manual cleaning carried out was more often a measure of

corrective maintenance for performance related failures than a preventive maintenance action.

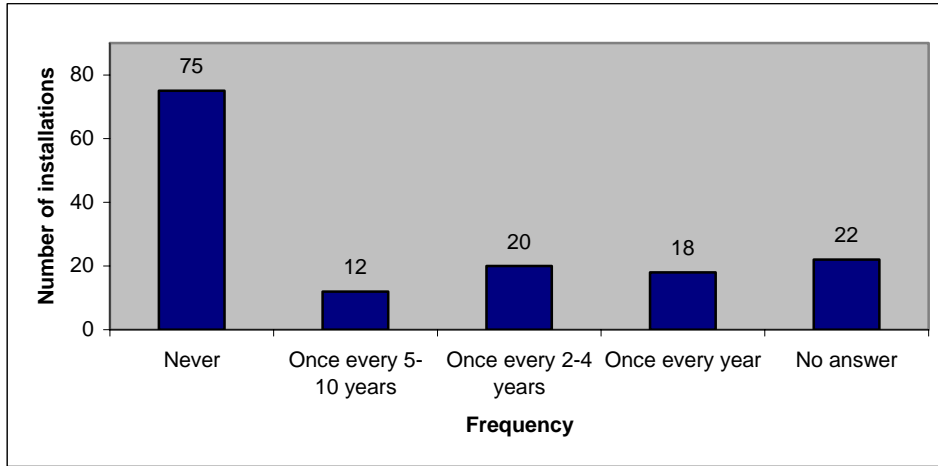


Figure 20 Frequency of manual cleaning

If manual cleaning was reported the respondents were also asked to answer the question: *What is the actual manual cleaning time?* The responses are presented in figure 21. The respondent was also asked if the platform staff carried out the cleaning themselves or if it was outsourced. Cleaning by platform staff was slightly more common than outsourcing.

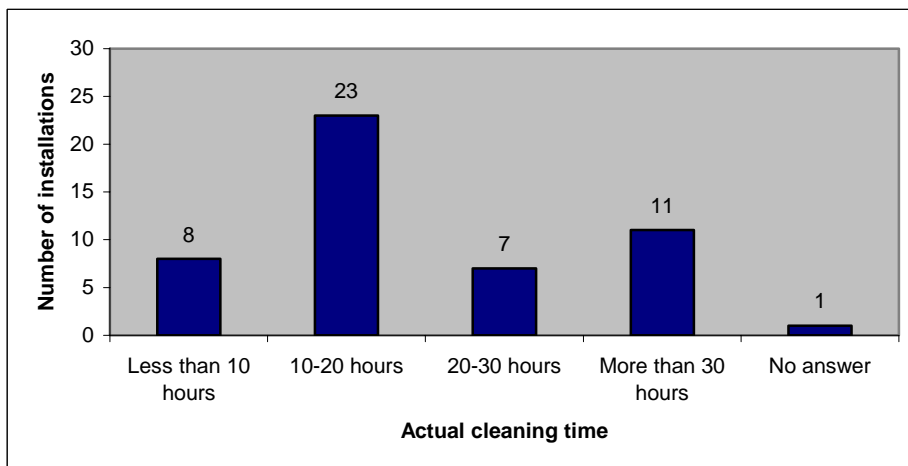


Figure 21 Manual cleaning time

5.3.3 Chemical cleaning

The same questions as for manual cleaning were asked regarding chemical cleaning. However, the response rates for questions regarding chemical cleaning were very low, which make the results for these questions less reliable. Diagrams will therefore not be presented.

A response to the question: *What is the chemical cleaning frequency?* was only received for 29% of the installations. Out of these, 82% answered *less than once per year*, 16% *once per year* and 2% *twice per year*. In the cases where none of the alternatives were chosen it is unsure whether no chemical cleaning is carried out or if the respondent did not know.

If chemical cleaning is done a majority reports that the platform does the cleaning themselves, as opposed to outsourcing, and that the cleaning time is most often more than 5 hours.

5.3.4 Spare parts and redundancy

For 69% of the surveyed installations no spare parts were reported. It is unclear whether there were no spare parts or if the respondent did not know. For the rest of the installations one or several kinds of spare parts were reported. The most common spare parts reported are gaskets. Numbers of spare parts reported are given below:

Do you have any of the following spare parts available...

Gaskets:18 installations

End plate with gasket: 7 installations

Plates with gaskets:10 installations

Full plate pack:17 installations

Standby unit: 10 installations

In cases where the respondents reported having changed gaskets and/or plates it was in all cases, except a very few, in the purpose of corrective maintenance. 90% of the installations are gasketed or semi-welded (a combination of gaskets and welds). Usually the change of gasket did not involve a change in type of gasket material or brand.

7% (10 installations) of the surveyed installations were reported to have a standby redundancy. The active redundancy is not possible to calculate from the collected data although it is estimated to be high. About half of the installations are operated with two or more units in parallel. In many cases production rates are lower than expected or has declined which will lead to overcapacity. As an example one of the respondents wrote:

“Due to the reduced crude flowrate, the three units are now typically operated with 2 units on duty, 1 in stand-by position.”

5.3.5 US installations

The respondents for US installations were asked: *What routines for preventive maintenance do you have?*

On 74% of the surveyed installations no preventive maintenance was done. The most common preventive maintenance is chemical cleaning. Manual cleaning is associated with corrective maintenance. Below are the respondents' descriptions of their preventive maintenance routines:

"Check differential pressure, when bad cleaning with paraffin solvent"

"Backflushing when rise in differential pressure. Need to keep an adequate velocity to prevent sediment on cold side. Manual cleaning about every 6 years (has been done twice so far), the manual cleaning is done by a contractor who takes the unit apart and power washes the plates removing sediment on cold side. Regasketing was done in 1997."

"Treat sea water with hydrochloride to prevent biological growth, manual cleaning of both sides every 3-4 years to remove fouling build-up, Alfa Laval field engineers do this work."

"Chemical cleaning every 6 weeks to 2 months (when the cooling medium does not get cool enough) when offline, each unit gets cleaned 3-5 times a year."

"Chemical cleaning every 6-12 months"

"Chemical cleaning when needed but not regularly"

"Periodic cleaning when performance degrades"

"Have had some problems with fouling previously but not since cleaning regularly"

30% of the installations have a standby redundancy.

5.4 End user attitudes on Alfa Laval reliability

The respondents were asked to give their personal opinion on the reliability of Alfa Laval products, support and the company in general. Response alternatives were "very reliable", "reliable", "unreliable" and "no opinion". 58 respondents participated in the survey.

5.4.1 Product reliability

88% of the respondents considered the Alfa Laval products to be very reliable or reliable. The responses are presented in figure 22.

Comments from respondents on product reliability reflected the positive response. A few of these are given below:

“We love the units out on the platform because they are working so well. I have worked at several platforms in Alaska and think that the PHEs are far and above better than the shell-and-tubes or fin-type heat exchangers. The units have handled 100 000 barrels a day continuously for 6 years without any problems which no other equipment on the platform has managed. The only drawback of PHEs is the initial expense.”

“The platform staff is impressed with the performance of the unit. We were sceptical to the plate and frame concept to begin with but are now very happy with the installation.”

“All in all, the exchangers have been reliable, and caused us no problems, thank you! We have enough other problems to worry about.”

“Equipment is working very well. In the future if necessary, new plates could be added following the platform request.”

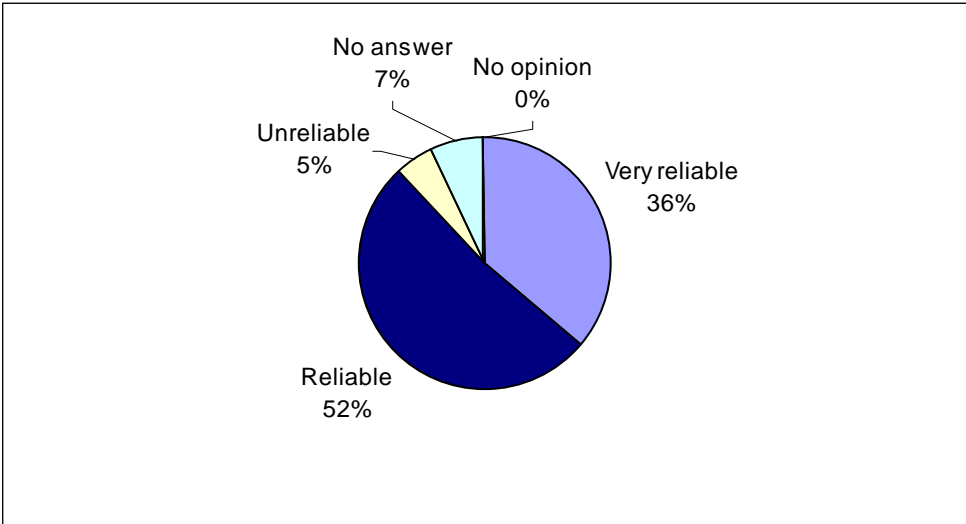


Figure 22 Respondents opinions on Alfa Laval product reliability

5.4.2 Reliability of support

The responses regarding reliability of Alfa Laval support is presented in Figure 22. Many of the respondents had never been in contact with Alfa Laval regarding support and did therefore not have an opinion about it. 9% of the respondents think the support is unreliable. Some respondents commented their dissatisfaction with the support and service. These comments are given below. Still 55% thought it was very reliable or reliable.

“Both units have now been in repair for about 5 months. It is frustrating with the long repair times and we want the units back on the platform.”

“I am satisfied with the performance and operation of the unit today but very unsatisfied with the Alfa Laval service on parts. It has been 2 months delivery time on parts which is too long.”

“Response to general operational/ spares enquiries poor and slow, require chasing up.”

“In general, it takes too long to get the units repaired by Alfa Laval. This issue has been discussed with our purchasing department and management within Alfa Laval.”

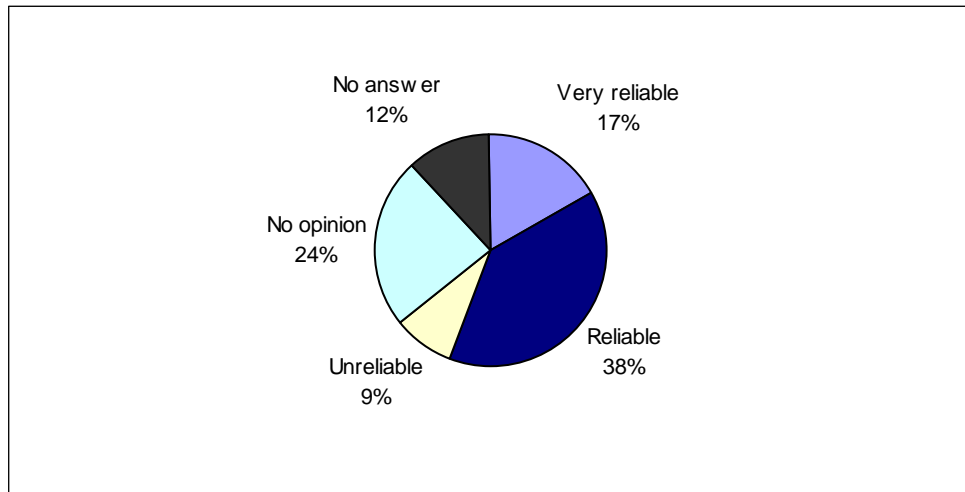


Figure 22 Respondents opinions on the reliability of Alfa Laval support

5.4.3 Reliability of Alfa Laval in general

The responses regarding the reliability of Alfa Laval as a company are presented in figure 23. 71% think the company is reliable or very reliable. None of the respondents consider Alfa Laval to be an unreliable company. However, a rather large group did not know the company at all. This was noticed when talking to respondents in the pre-survey contacts.

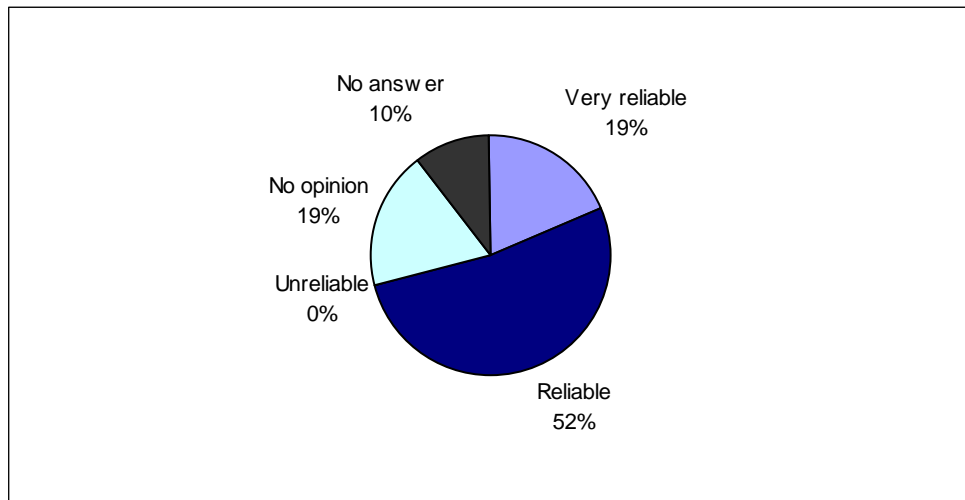


Figure 23 Respondents opinions on Alfa Laval reliability in general

5.5 Other observations

At the end of the questionnaire the respondents were asked to share any additional comments or recommendations. Many of them used this opportunity and gave valuable information. Comments from respondents were also given during the pre-survey contacts and observations were made. Some typical observations exemplified with comments are presented below:

A problem in collecting the reliability data was to obtain reliable historic data. The staff turnover was noticed to be high out on the platforms. A common reaction from respondents when asked to participate in the survey was something like: Well, I am quite new here but I will try to find out the information for you. One respondent also commented this on the questionnaire:

"It is difficult to obtain exact historic information due to extensive turnover of personnel. The unit was commissioned before computers were used to log maintenance. In general these coolers are working very well."

The response when contacting respondents were generally positive and as shown in previous sections a vast majority consider the plate heat exchangers to be reliable. When asked to participate in the survey one process engineer said: *"Why are you doing a reliability survey on plate heat exchangers? They are the only things that do not break down on a platform."*

Although most installations did not have any reported failures there were a few with serious and recurring failures. The recurring failures were often due to a lack of identifying the root cause of the problem, which can lie outside of the heat exchanger. In several cases failures have been caused by unsuitable set-up of the installation or design of process.

One example is a crude oil interchanger, installed in 1997, which had an unexpected performance due to paraffin build-up on the plates. As a first step cleaning with paraffin solvent was tried. Increasing problems despite cleaning did that all plates had to be replaced in 2000. The respondent says: *“The problems are caused by a failure on the plant waste heat system and a bad set-up of the installation. The heat exchanger was not to blame for the problems.”*

Another example is a crude oil cooler with continuous fouling problems. The respondent says that: *“The design of the plant placed the filter after the cooler instead of before, which does not help with regard to blockages.”* To place a filter before the unit may have solved the problem.

There are also examples of heat exchangers used for another purpose than it was designed for. The importance of correct design for individual process conditions was mentioned in chapter 3. If the heat exchangers are used in other conditions than designed for there will be no guarantee for reliable performance.

In section 3.3.1 it was mentioned that: whether a gradual performance reduction is considered a fault or not depends not only on the degree of performance reduction and the specific requirements but also on the operator’s/customer’s expectation and perception of failure.

Although unexpected performance due to fouling were commonly reported as a failure there were also cases of fouling not considered a failure but rather something that is expected to happen sooner or later. One respondent said:

“Fouling is noticed by a temperature increase on the cooling water side. I don’t consider the fouling as a failure. Fouling is expected in equipment in continuous services in dirty processes.”

6 DISCUSSION AND CONCLUSIONS

In this chapter the results for the specific areas of interest are discussed and answers to the specific questions given. Conclusions are made based upon the results and research framework. Finally an evaluation of the method and the project as a whole is given.

6.1 Failure data

6.1.1 Occurrence of failure and failure rate

For 65% of the surveyed installations, respondents reported no failures, 25% one failure and only 10% two or more failures. The majority of the installations have been operating in tough conditions for several years, mean number of years in operation for surveyed installations is 6,3 years. This is a very positive result, although the reported failures should be seen as a minimum of failures because there may be failures that are unknown to respondents. This will be discussed further below.

In the previous chapter it was found that the individual estimated failure rates for the 147 surveyed installations based on reported failures vary between 0 and 150 failures/ 10^6 h with 93% under 60 failures/ 10^6 h. As a comparison, 114 failures/ 10^6 h correspond to one failure a year.

The average failure rate based on reported failures was estimated to 6,14 failures/ 10^6 h.

Comparing estimated failure rate values of different surveys might be misleading because of possible differences in the component boundary definition, the failure definition and the surveyed population. Results from other surveys is still of interest.

The estimated failure rate (for homogenous sample) for the PHEs in the OREDA (Offshore reliability data) survey was 66,35 failures/ 10^6 h. What is interesting is that this value is significantly lower than the estimated failure rate for the group of all heat exchangers which was 100,58 failures/ 10^6 h.

The difference between the results of the OREDA survey and this survey could possibly be that the OREDA survey includes minor failures, which respondents have not reported in this survey. Another difference between the surveys is that this survey covers a much larger population. The difference between the results seems less though, when comparing with the estimated failure rates of rotating machinery (OREDA survey), which are in the range of 600-1200 failures/ 10^6 h.

In the reliability survey carried by Alfa Laval on plate heat exchangers in the power industry the estimated failure rate was only 2 failures/ 10^6 h. The equipment boundaries and failure definition for this survey is unknown. The explanation for the lower failure rate could be that these heat exchangers are utility heat exchangers with more favourable process conditions than the process heat exchangers.

As mentioned earlier estimated failure rates are based on the assumption of a constant failure rate. In figure 14, section 5.2.1 individual estimated failure rates were plotted against the age of the installation. It was noticed that the average of estimated

individual failure rates based on reported failures do not correspond to a constant average failure rate. For installations more than 10 years of age, failure rates drop significantly.

The most likely explanation for this is that the collected data does not include all failures during the useful life phase. Historic failure data is not reliable and therefore because of extensive turnover of personnel and that many units were installed before computers were used to log maintenance. This means that recent failures are more frequently reported than older ones leading to a higher failure rate for younger installations.

The estimated failure rate of this survey, 6,14 failures/ 10^6 h, should therefore be seen as some kind of minimum value. Even if the true value were the double or several times higher it would still correspond to much less than one failure a year.

The most important conclusions are that a majority of the users of plate heat exchangers in oil and gas processes have not experienced any failure of the equipment and that the reliability of plate heat exchangers is at least as good as other types of heat exchangers operating in oil and gas processes.



Figure 24 One of the plate heat exchangers in the survey installed in gas compression process

6.1.2 Fault modes and failure causes

External leakage was the most commonly reported fault with 45 % of the failures. The fault was generally due to gasket wear-out or gasket blow-out.

The high number of external leakages due to gasket wear-out is no surprise considering that regasketing is seldom reported to be carried out for preventive purposes although Alfa Laval recommends it. Gaskets will wear out sooner or later causing an external leakage if not replaced prior to gasket failure. Whether the users

know about this but rather wait with regasketing until failure or if they are unaware about gasket lifetime is not known. In the cases when gasket wear-out is reported after only one year, it can be due to incompatible gaskets or that the gasket has been damaged, not worn out.

Both pressure shocks and continuous pressure variations are mentioned as reasons for gasket blow-out. In many cases the reasons for gasket blow-out seems to be unknown to the users. There are several cases where there have been recurring gasket-blow-out failures because the corrective action only includes regasketing and no elimination of pressure spikes.

Unexpected performance, generally a performance reduction, due to fouling was the second most commonly reported fault (32%) and fouling was the individually most common failure cause. Whether a gradual performance reduction is considered a fault or not depends not only on the degree of performance reduction and the specific requirements but also on the user's expectations and perception of failure.

Internal leakage was the least reported fault accounting for 23% of the failures. Reported causes of internal leakage are fatigue, erosion, corrosion, damage of plates and gasket failures. However, a gasket failure cannot cause an internal leakage by itself. In these cases, what is most likely is that the respondent have confused internal leakage with external leakage. A number of reported internal leakage faults are therefore probably external leakages. It is noteworthy that there was only one case of corrosion reported, which has been found as a major problem for shell and tube heat exchangers by the SINTEF survey presented in 3.5.2.

For a rather large part of the failures the failure cause was unknown to the respondent. This is probably due to the extensive turnover of personnel, which has been mentioned earlier. If failure causes are not identified and saved for future references the risk of the same failure occurring again increases.

As mentioned in section 3.3.1, a PHE is a piece of static equipment that cannot create pressure surges, temperature changes, plugging solids or scale by itself. If properly designed, failure causes are therefore the result of either none or incorrect maintenance, or unsuitable operating conditions which the survey have given many examples of.

6.1.3 Corrective maintenance and failure influence on production process

Reported external leakages are generally corrected either by replacement of gaskets or replacement of plates. Since external leakages are caused by gasket failure (for gasketed units) it is unexpected that replacement of plates is such a common corrective maintenance action. The majority of external leakages had no influence on the production process. The rest were approximately split in half causing reduced capacity or shutdown.

Corrective actions reported for internal leakages are most often replacement of plates although replacement of gaskets is also reported in several cases. As mentioned in previous section, an internal leakage cannot be caused by a gasket failure alone and gasket replacement is therefore not enough to correct the failure. And as also

mentioned before it is therefore likely that the respondent have confused internal leakage with external leakage. Otherwise, an inaccurate corrective maintenance action has been chosen. Internal leakages caused “no influence on the production process” respectively “shutdown of process” in 38% each of the cases. For the rest of the cases, 24%, reduced process capacity was reported.

For unexpected performance faults, cleaning and sometimes replacement of plates are the reported corrective maintenance actions. In the cases where plates have been replaced it is likely that fouling material is sticking to the plates making them difficult to clean. There are also examples of when plates have been damaged during cleaning and then needed replacement. The cleaning carried out as corrective maintenance is manual cleaning in a majority of the cases. As for the influence on the production process, unexpected performance faults caused a reduced process capacity in half the cases and the other half had no influence on the production process.

Overall the most common corrective action reported was replacement of a few or all plates (including gaskets), second was cleaning of the unit and third was replacement of gaskets. Considering that gasket failure was a much more commonly reported failure cause this result is quite surprising. The replacement of plates is more expensive than the replacement of gaskets and would therefore be expected to be preferred by the operator.

Serious and recurring failures are often due to a lack of identifying the root cause of the problem, which can lie outside of the PHE. A lot of money and frustration will be spent on short-term solutions instead of correcting the root cause of the problem. Examples are a) recurring external leakages due to gasket blow-out of pressure shocks in the system which are “corrected” by repeated replacement of gaskets b) internal leakages caused by fatigue due to continuous pressure variations “corrected” by the replacement of plates. c) severe fouling problems which are “corrected” by repeated manual cleaning and not the installation of a filter.

In the cases where the root cause was found after a long time a lot of money and frustration could have been saved if a deeper analysis of the problem had been done initially. Lack of knowledge is probably a fundamental factor in why this has not been done.

Because of the high economic implications of an unplanned shutdown it is important to know the reported failures’ influence on the production process. Out of the total reported failures, 16% reported a process shutdown as the failure influence on the process. The majority of all reported failures, 56%, did not have any negative influence on the production process at the platform. Whether a failure will cause a shutdown or not is not only depending on the criticality of the failure but also on available redundancy. So, in the cases when failure have had no influence on the process either a partial fault has been present and corrective maintenance could be delayed until planned shutdown or redundancy was utilized.

The remaining 28% of the failures were reported to have caused a reduced capacity of the process. In this case it can either be a reduced performance of an installation or that one of several parallel units have been taken offline.

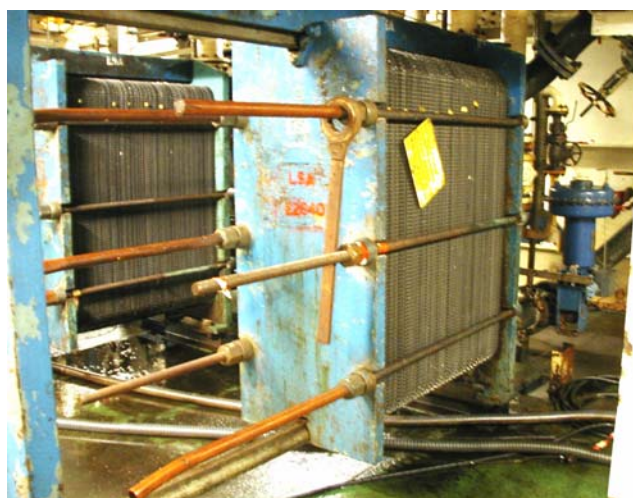


Figure 25 Two of the surveyed plate heat exchangers installed in 1978 in crude oil dehydration process

6.2 Preventive maintenance

Maintenance practices vary broadly between the oil and gas companies but generally no or little preventive maintenance is carried out regularly. Opening the unit for inspection, manual cleaning and the replacement of parts are all most often carried out on units that currently have or recently had failures.

This may be a sign of the general trend towards condition based maintenance, which means that preventive maintenance is not carried out in predetermined intervals, but i.e. based on performance and/or parameter monitoring. As an example of this, respondents have mentioned backflushing or chemical cleaning when an increase in differential pressure is noticed. Condition based maintenance generally lead to longer intervals between maintenance operations and in turn a reduction of both maintenance costs and maintenance induced failures.

Although it is clear that preventive maintenance could have prevented many of the reported failures from occurring it may be more economical for the operator to wait until a failure occur and then correct it.

Many failures, such as leakages, are however not possible to expect based on performance and/or parameter monitoring and therefore maintenance many times becomes more of a corrective than preventive action with this strategy. (It should be kept in mind though, that whether maintenance is seen as preventive or corrective is determined by the definition of failure.) At the same time there is the risk of unavailability if a sudden failure needs immediate repair and no redundancy is available.

From the collected data it is difficult to tell which is the most common preventive maintenance action, because of non-response problems, although chemical cleaning

seem to be more of preventive character and manual cleaning more corrective. As mentioned above, the replacement of gaskets were in almost all reported cases in the purpose of corrective maintenance, not complying with the Alfa Laval advice of planned regasketing prior to gasket failure. Usually the change of gasket did not involve a change in type of gasket material or brand.

For 69% of the surveyed installations no spare parts were reported. It is unclear whether there were no spare parts or if the respondent did not know. The most common spare parts reported are gaskets and next full plate pack.

6.3 End user attitudes on Alfa Laval reliability

When is a product reliable enough? One way of answering this question could be: when the users of the product consider it reliable.

Of the 58 respondents that participated in the survey as many as 88% considered the Alfa Laval PHE to be a reliable or very reliable product. Of course this is a very good result for Alfa Laval, although not very surprising considering that the majority reported no failures. Some respondents also expressed a preference for PHE in favour of other types of heat exchangers.

5% of the respondents considered the product to be unreliable. These were naturally often the users of installations with recurring or continuous problems.

24% of the respondents specified that they did not have an opinion on Alfa Laval support, which is because they don't have any experience of it. 55% considered the support to be reliable or very reliable and 9% considered it to be unreliable. It seems like the customer satisfaction of the support varies a lot between respondents. It is possible that there are differences in the support given in different regions but the explanation is probably more due to the subjective experience.

Complaints on the support is generally concerned with time. Both repair times and delivery times on parts are too long according to some respondents.

The responses regarding the reliability of Alfa Laval as a company were positive. 71% think the company is reliable or very reliable. None of the respondents consider Alfa Laval to be an unreliable company. Interesting is that a rather large group did not know the company and therefore had no opinion. It was clear that the company was less known to the respondents outside of Europe. This was also noticed when talking to respondents in the pre-survey contacts.

Overall, the end users' attitudes and perceptions of the reliability of Alfa Laval and its products and support are very positive.

6.4 Improvements on field reliability

Considering the results of this survey, the need for improvement of field reliability can be discussed. A majority of the end users have not experienced any failure of the equipment and seem to be satisfied with the installations. Heat exchangers in general have a considerably lower failure rate than many other types of topsides equipment.

Maybe the reliability at present is just good enough? In any case there are a few points to be made.

As earlier mentioned, reliability in the field is based upon good practice in installation, operation and maintenance of equipment. The results from the survey indicate that failures arise because of problems in these areas. Following the Alfa Laval instructions on operation and maintenance (section 3.3.2) would probably have prevented most failures. In many cases a fairly inexpensive and simple solution will prevent failure, for example using a slow valve to avoid pressure shocks or installing a filter to prevent fouling.

So, why are not the operators following the instructions? Good practice in installation, operation and maintenance requires a good knowledge of the equipment and how to handle it. In order to follow the instructions they need to be aware of them. The instruction manual is probably not read by most of the users. In addition, knowledge on plate heat exchangers is not yet established as for the traditional shell and tube technology. If operators had the basic knowledge, easily avoidable failures would be prevented and the right corrective actions chosen preventing recurring failures. Users learn by experience and knowledge generally increases with time but the extensive turnover of personnel leads to loss of knowledge. Established routines and maintenance records would prevent this loss.

Lack of knowledge is however only one part of the explanation. Optimising maintenance strategies requires not only a good knowledge of the equipment but also consideration of all effects, both good and bad, and costs of maintenance activities. Even if the operators knew about all instructions there is no guarantee that they would act in accordance with them. Results from the survey have shown that most operators rather wait until a failure happens rather than preventing it. Whether this is due to a lack of knowledge, low priority or the preferred policy in spite of knowledge is unknown. (The trend of condition-based maintenance replacing planned preventive maintenance is possibly an explanation.) If waiting until a failure occurs and then correct it, is preferred over planned preventive maintenance the availability of spare parts and redundancy become much more important in order to reduce the risk of an unplanned shutdown.

What role does Alfa Laval have in facilitating the reliability improvement of plate heat exchanger operation in the field?

Alfa Laval needs to make sure to offer and supply operators with knowledge on operating instructions and maintenance. Instruction manuals should be easily read and updated regularly. Maybe an interactive instruction CD would be more interesting than a regular manual. There are nevertheless difficulties in increasing the operators' knowledge. The extensive turnover of personnel is one difficulty, another one is that the operators may be unwilling to learn.

Alfa Laval should not only offer knowledge and support at the time of delivery but also follow up the equipment after some time. This would also be an opportunity to sell additional equipment and spare parts, for example filters or gaskets.

When the operator choose to use Alfa Laval support and service it is very important both that the root cause of a problem is identified and that it is corrected as soon as possible. This has not always been the case, which has been exemplified by specific cases in the survey.

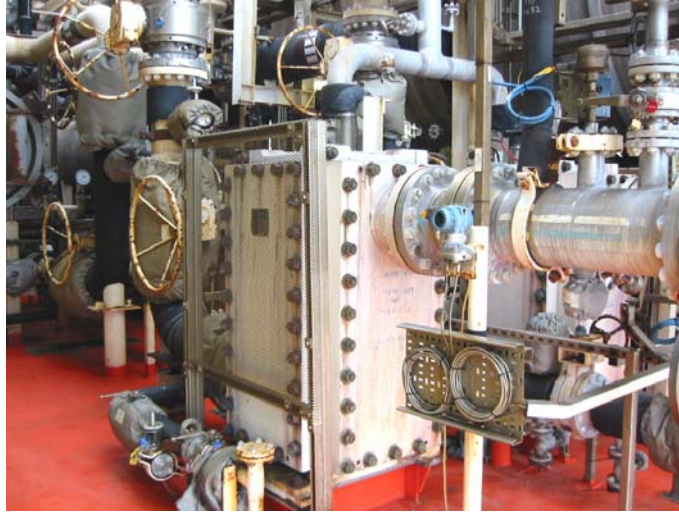


Figure 25 One of the plate heat exchangers in the survey installed in crude oil dehydration process

6.5 Generalisability and limitations

The surveyed population is considered to fairly well represent the target population in terms of the distribution of processes and geographical regions. The results and conclusions are therefore considered to be applicable for the target population.

The main oil and gas processes found offshore are identical or similar to the ones found at onshore plants which is why, although not directly applicable, the results of this survey also give an indication on the reliability of PHEs in onshore oil and gas processes. But in order to get more valid results for onshore installations, additional research is needed.

This survey has not dealt with possible differences in reliability of different regions or different processes, which may be of interest for further research.

6.6 Project evaluation

The main objective of this project were to evaluate the reliability of plate heat exchangers in offshore oil and gas processes, with main focus on failure data, through the collection and analysis of operational data from end users.

Detailed objectives were:

- ✓ Create a common language for the concept of reliability within Alfa Laval Oil & Gas Technology
- ✓ Sharing of real life operational experience in a systematic way by creating a reliability database
- ✓ Exploring possible improvements of field reliability
- ✓ Provide input to marketing material such as case stories and technical paper
- ✓ Possibility of using the evaluation for benchmarking

To what degree have these objectives been reached? To start with the detailed objectives:

- ✓ The reliability theory of this report has provided essential definitions and concepts, which is a basis for meaningful discussion of reliability issues.
- ✓ All collected data have been stored in a database, which will be available for Oil & Gas Technology employees around the world. This means sharing of operational experiences from 174 installations.
- ✓ The need for and suggestions on how to improve field reliability has been discussed based on the results of the survey. The feedback from the users also gives a possibility to analyse specific cases in need of improvement.
- ✓ The collected data and this report will be used as input for marketing material such as a technical brochure.
- ✓ Although a direct comparison of reliability data from different surveys can be misleading, conclusions and indications can be used for benchmarking of different technologies.

As for the main objective, reliability data from 174 installations have been collected from end users and analysed. Main focus has been on failure data and research questions within these areas have been answered based on the collected data. Practices of preventive maintenance and end user attitudes of Alfa Laval reliability have also been surveyed.

The weakness of the survey has mainly been the problem of finding respondents and achieving reliable historic reliability data. But, as has been noticed by previous researchers in the field, sufficient and reliable field data is very difficult to acquire. It is doubtful that other methods would have given more reliable data. In any case it would be impossible to measure because there is no way to find out how much data is missing.

Looking back, there are a however few changes in the research design that could have been done to increase the reliability and validity of the data. One of these things is to carry out a small-scale pilot survey, i.e. test the questionnaire on a few respondents

before the real survey, giving an opportunity to make changes based on their comments and answers.

Making the original questionnaire shorter may have increased the response rate. As the survey progressed it was noticed that many of the questions were unnecessary. The shorter questionnaire, which was used for the US installations, worked well.

Overall, the project has given a lot of valuable feedback on the reliability and operation of the Alfa Laval plate heat exchangers in offshore oil and gas processes.

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Figures

Figures with no reference come from Alfa Laval or is made by the author.

APPENDICES

Appendix 1: Definitions

Unless other source is given the definitions are adapted from *Maintenance Terminology*. European Standard 13306:2001.

Active redundancy. Redundancy wherein all means for performing a required function are intended to operate simultaneously

Availability (performance). Ability of an item to be in a state to perform a required function under given conditions at a given instant of time or during a given time interval, assuming that the required external resources are provided.

NOTE: This ability depends on the combined aspects of the reliability, the maintainability and the maintenance supportability.

Corrective maintenance. Maintenance carried out after fault recognition and intended to put an item into a state in which it can perform a required function.

Degraded state. State of an item whereby that item continues to perform a function to acceptable limits but which are lower than the specified values or continues to perform only some of its required functions.

Dependability. Collective term used to describe the availability and its influencing factors: reliability, maintainability and maintenance supportability.

Fault. State of an item characterized by inability to perform a required function, excluding the inability during preventive maintenance or other planned actions, or due to lack of external resources.

Fault mode. Method by which the inability of an item to perform a required function is established.

Failure. Termination of the ability of an item to perform a required function.

Failure cause. Reason leading up to a failure.

Installation. One or several identical heat exchanger units used in the same service.⁹⁹

Maintainability. Ability of an item under given conditions of use, to be retained in, or restored to, a state in which it can perform a required function, when maintenance is performed under given conditions and using stated procedures and resources.

Maintenance supportability. Ability of a maintenance organization of having the right maintenance support at the necessary place to perform the required maintenance activity at a given instant of time or during a time interval.

Partial fault. Fault characterized by the fact that an item can only perform some but not all of the required functions.

⁹⁹ Tobias Svensson

NOTE: In some case it may be possible to use the item with reduced performance.

Preventive maintenance. Maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure.

Process conditions. The conditions of the process that the heat exchanger operates in such as temperature, pressure, flow rate and fluid composition.¹⁰⁰

Rate of occurrence of failure. Number of failures of an item in a given time interval divided by the time interval.

Redundancy. In an item, the existence of more than one mean at a given instant of time for performing a required function.

Reliability. Ability of an item to perform a required function under given conditions for a given time interval.

S-confidence. Statistical confidence, the exact fraction of times the confidence interval will include the true value, if the experiment is repeated many times. S-confidence takes no account of engineering or process changes, which might make sample data unrepresentative.¹⁰¹

Service. The purpose of the heat exchanger, e.g crude oil heater, natural gas cooler etc.¹⁰²

Standby redundancy. Redundancy wherein a part of the means for performing a required function is intended to operate, while the remaining parts of the means are in operating until needed.

Unit. One heat exchanger¹⁰³

Upstream. Collective term for oil and gas operations carried out in order to explore oil and gas and to produce it to a quality acceptable to the downstream sector (refineries), power plants etc.¹⁰⁴

Useful life. Under given conditions, the time interval beginning at a given instant of time and ending when the failure rate becomes unacceptable, or when the item is considered unreparable as a result of a fault or for other relevant factors.

¹⁰⁰ Tobias Svensson

¹⁰¹ O'Connor, Patrick D.T. (1991) *Practical reliability engineering*.

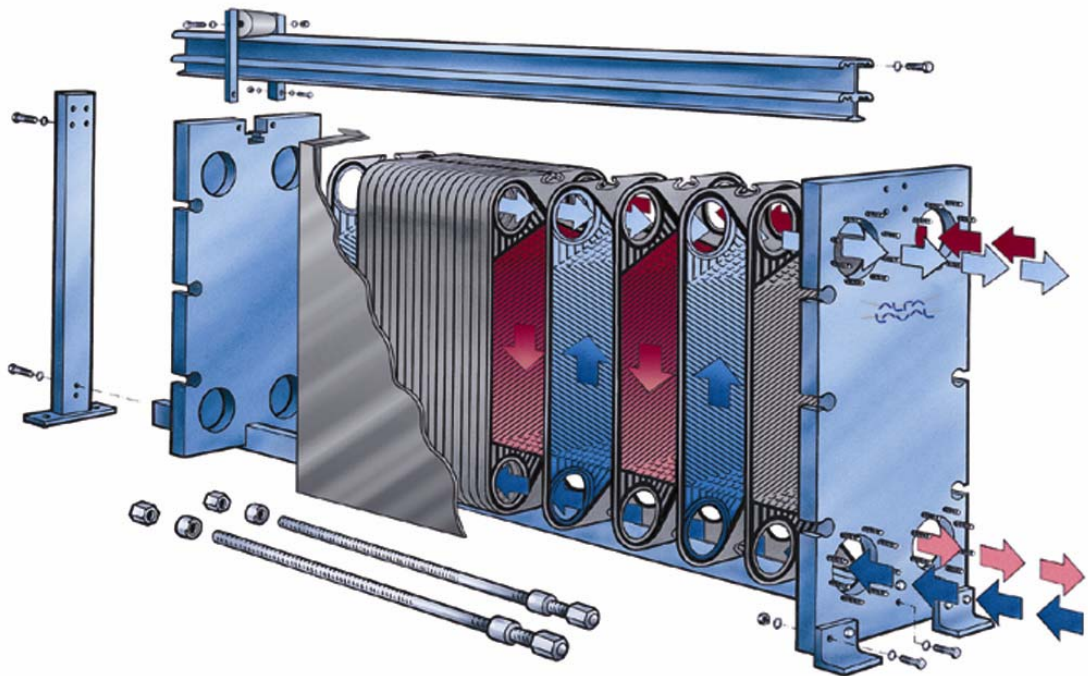
¹⁰² Tobias Svensson

¹⁰³ Ibid

¹⁰⁴ Ibid

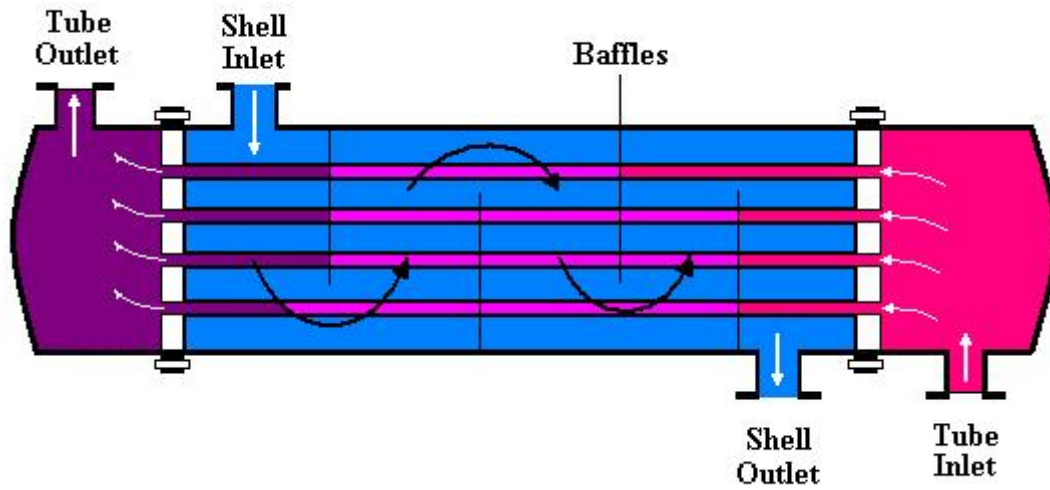
Appendix 2: What is a plate heat exchanger?¹⁰⁵

The basic plate heat exchanger consists of a series of thin, corrugated plates that are gasketed or welded together (or any combination of these) depending on the liquids passing through and on whether it is practical to be able to subsequently separate the plates, for whatever reason. The plates are then compressed together in a rigid frame to create an arrangement of parallel flow channels. One fluid travels in the odd numbered channels, the other in the even.



¹⁰⁵ Alfa Laval – plate technology. Alfa Laval. 2002.

Appendix 3: What is a shell and tube heat exchanger?¹⁰⁶



¹⁰⁶ <http://www.me.wustl.edu/ME>.

Appendix 4: Original questionnaire

Reliability study of Alfa Laval plate heat exchangers in the oil and gas industry

Plant Name:	Duty:
Country:	Tag No:
Type of PHE:	
Serial No:	
Plate material:	
Field gasket material:	Glued <input type="checkbox"/> Clip-on <input type="checkbox"/>
Ring gasket material:	

Operation

- Start-up year
- What type of installation was it?

New plant <input type="checkbox"/>	Plant expansion <input type="checkbox"/>	Replacement <input type="checkbox"/>
------------------------------------	--	--------------------------------------

If replacement, what kind of equipment was used before?

Alfa Laval plate heat exchanger	<input type="checkbox"/>
Other plate heat exchanger	<input type="checkbox"/>
Shell and tube heat exchanger	<input type="checkbox"/>
Other	<input type="checkbox"/>
- Why was it replaced?
- Is the unit still in operation?

Yes <input type="checkbox"/>	No <input type="checkbox"/>
------------------------------	-----------------------------

If not, what year did it go out of service?

Why was it taken out of service?
- Has the unit been rebuilt?

Yes <input type="checkbox"/>	No <input type="checkbox"/>
------------------------------	-----------------------------

If yes, what year/s?

Why was it rebuilt?
- What is the type of operation?

Continuous <input type="checkbox"/>	Back-up <input type="checkbox"/>
-------------------------------------	----------------------------------

If back-up, what is the typical working schedule?

< 2 times/year	<input type="checkbox"/>
2-5 times/year	<input type="checkbox"/>

> 5 times/year

- What is the normal inlet operating temperature at the hot side? (Please, fill in unit)
- What is the normal operating pressure at the hot side? (Please, fill in unit)
- What is the normal operating pressure at the cold side? (Please, fill in unit)

Process

- What is the filter mesh size... at the hot side? (Please, fill in unit)
at the cold side? (Please, fill in unit)

- **Closed loop cooling**

Do you chlorinate the sea water?

Continuously Intermittent No

- **Crude dehydration (specific questions)**

What is the duty?

Dry crude cooler
Dry / wet crude interchanger
Produced water cooler
Produced water/ wet crude interchanger
Wet crude heater
Other

What type of oil is it?

Aromatic
Sweet Sour

Is there a vessel (separator / free water knock-out/ slug catcher, etc) before the unit?

Yes No

Do you have waxing?

Yes No Unknown

Do you have slugging?

Yes No Unknown

- **Gas compression (specific questions)**

What is the duty?

Pre-compressor gas cooler
Interstage gas cooler
Recycle gas cooler
Other

What type of compressor do you have? Centrifugal Reciprocal

What side of the compressor is the cooler? Suction side Discharge side

Do you have cycling? Yes No Unknown

➤ **Gas sweetening (specific questions)**

What is the duty? Lean / rich interchanger
 Lean cooler
 Condenser
 Reboiler
 Other

What type of solvent do you use and what is the concentration?

➤ **Gas dehydration (specific questions)**

What is the duty? Lean / rich interchanger
 Lean cooler
 Condenser
 Other

➤ **Other process (specific questions)**

What is the duty?

Preventive maintenance

➤ Has it been required to open the unit for inspection? Never
 Once every year
 Once every 2 years
 Once every 3 years
 Once every 4 years
 Once every 5 years

➤ Manual cleaning:

What is the frequency? Never
 Once per year
 Once every 2-4 years
 Once every 5-10 years

What is the actual cleaning time? < 10 hours
10-20 hours
20-30 hours
>30 hours

Who does the cleaning? Ourselves Outsourcing



Chemical cleaning:

What is the cleaning frequency? Less often than once per year
Once per year
Twice per year

What is the actual cleaning time? < 5 hours > 5 hours

Who does the cleaning? Ourselves Outsourcing

Have you had any regasketing/ reconditioning done? Please fill in year, type of gasket and gasket brand! Please, only use alternatives given.

Year	Type	Brand
	Same as before NBR (Nitrile) HNBR (Hydrogenated Nitrile) EPDM ALEPDM FPMG (Viton) Other	Alfa Laval Other

➤ Have you changed plates? Please fill in what year/s!

➤ Do you have any of the following spare parts available...

- gaskets?
- end plate with gasket?
- plates with gaskets?
- full plate pack?
- stand-by unit?

Failures

➤ Please fill in failure information! Choose an alternative in the first row and fill in one row per failure!

Year	Type of failure	Reason	Time of detection	Corrective actions	Process influence
xxxx	1 External leakage 2 Internal leakage 3 Unexpected performance 4 Unknown	1 Corrosion 2. Damage by foreign object 3 Erosion 4 Fatigue 5 Fouling build-up 6 Gasket blow-out 7 Gasket incompatibility 8 Gasket worn out 9 Plugging 10 Wrong re-assembly 11 Wrong supply 13 Other (pls specify) 14 Unknown	1 Commissioning 2 Start-up 3 Shut-down 4 Normal operation 5 Other circumstances 6 Unknown	1 Cleaned the unit 2 Repaired the welds 3 Replaced gaskets 4 Replaced plates 5 Replaced the unit with other PHE 6 Replaced the unit with a shell & tube 7 Other (pls specify) 8 None	1 Emergency shut-down 2 None, until planned shut-down 3 Reduced capacity

General

- What is your opinion on the reliability of the Alfa Laval...

	Very reliable	Reliable	Unreliable	No opinion
product?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
support?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
company?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

- Please share any additional comments or recommendations below or on a separate sheet!

Name and e-mail:

Area of responsibility:

Date:

Thank you!

Appendix 5: Questionnaire for US installations

Reliability study of Alfa Laval plate heat exchangers in the oil and gas industry

Plant Name:	Tag No:
Type of PHE:	Serial No:

- What year did the PHE go into operation?
- What is the service? (e.g. crude cooler)
- What are the fluids? hot side cold side
- What routines for preventive maintenance do you have?
- Have there been any failures on these unit/s? Yes No
- Please describe each failure in table below

Year	Failure description and reason	Corrective actions	Process influence
What year was the failure detected?	What is the type of failure and what caused it?	What was done to correct the failure?	Please choose an alternative! 1 Emergency shut-down 2 None, until planned shut-down 3 Reduced capacity

- What is your opinion on the reliability of the Alfa Laval...
Very reliable Reliable Unreliable No opinion

product?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
support?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
company?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

➤ Please share any additional comments or recommendations below

Name and e-mail:
Area of responsibility:
Date:

Thank you!
