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Optimisation of heat exchanger networks maintenance

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The paper focuses on assessment and selection of individual and combined reliability, availability and maintenance software packages applicable to heat exchanger networks (HENs). A proper choice should be made considering the tools and features required. Based on the analysis and experience with software packages this contribution provides reasons why and when to apply them and the main features that need to be taken into account. The efficiency of complex reliability software in optimisation of HEN maintenance is demonstrated by a case study.

1. Introduction

A wide range of industrial processes apply heat exchangers as components of energy exchange. Different HENs have different maintenance issues. The various failure causes and features that affect HEN maintenance can be highlighted and system reliability analyses be performed with software tools support. Individual heat exchangers and those arranged in HENs have different maintenance characteristics. Fouling is one of the most important issues. It varies depending on the heat carrying media and heat exchanger design. Self-cleaning heat exchangers exist as well. The significance of modelling the behaviour of the heat transfer surface by using the fouling resistance factor increased recently. Some of the approaches are either being validated or modified to suit current design and optimisation techniques (e.g. Georgiadis et al., 2000; Markowski et al., 2005).

There are several kinds of features to be optimised in HEN maintenance. The balance of reliability and maintainability should be found as maintenance costs are generally lower than loss opportunity costs. Various types of software packages are used for modelling, simulation and optimisation of HENs. Maintenance issues can be modelled, simulated and optimised by a range of methods supported by software, and including non-destructive methods, Computational Fluid Dynamics (CFD), and optimum maintenance planning. Fouling mitigation strategies can be modelled by Fuzzy-Logic Expert Systems (FLES) software. Advanced analyses can be performed by Reliability, Availability, Maintainability and Safety (RAMS) software and specific reliability software tools, e.g. *Relex Reliability Studio* (Relex Software Corp.), *ITEM Toolkit* (ITEM Software), *BlockSim* (Reliasoft Corp.), *Weibull++* (Reliasoft Corp.). The proper choice of RAMS software depends on many factors (e.g. the place of application, the amount of provided

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data, calculation precision). Most of these tools can be tried out as a trial version for free. A detailed description was introduced by Sikos and Klemeš (2008).

Specific HEN design software tools cannot be used for RAM analyses. Dynacomp Inc. (2009) has developed several engineering software for heat exchangers. *Shell-&-Tube* is an integrated software package for heat exchanger design and cost estimation. *SinglePhase* optimises the design and operation HENs by analysing various possible arrangements. *HENCO* is another product of Dynacomp Inc. It is a HEN optimiser to financially optimise network configurations. *WS.HEN-Explorer* by Weel & Sandvig (2009) is a HEN optimiser in retrofit and new design. *The Heat Exchanger Network*, abbreviated as *THEN*, is a HEN synthesis program that was developed by Knopf et al. (1989, 2001) at Louisiana State University, USA. It integrates the networks of heat exchangers, boilers, condensers and furnaces for best energy utilisation. The pinch technology is applied as the basis for designing HENs. *Supertarget* is a heat integration and retrofit optimiser (2009). Aspen Technology Inc. has several modelling and optimisation products too (2009). Liporace et al. (2001) compared the total annual cost of HENs synthesized by various software tools, including *AtHENS*, a Matlab-Fortran environment. Maintenance costs as well as the HEN throughput can be considerably reduced by when a most appropriate and efficient SW tool is selected and implemented. The balance between maintenance costs and loss opportunity costs can be optimised via cost benefit analysis. Maintenance policies can be considered through the cohesive modelling modules and simultaneous analyses. Total system approaches contribute to the optimisation of design targets for plants to improve equipment selection, replacement, maintenance, as well as to increase system reliability. This presentation analyses some of the listed issues, makes suggestions and demonstrates an efficient use of selected software tools for maintenance optimisation.

2. Reliability and maintenance of heat exchanger networks

The main deficiency of HEN synthesis is the assumption of constant operating conditions, which in practice might change. Operational maintenance, availability and cost are important factors of HENs.

Some definitions should be introduced before examining Reliability, Availability and Maintainability (RAM) issues. *Reliability* is the probability that the HEN will perform satisfactorily for at least a given period of time when used under certain conditions (Ireson et al, 1996). The *availability* of a heat exchanger network represents the capability to manage heat and power streams continuously in a usual and regular way. *Maintenance* covers the activities undertaken to keep the HEN operational (or restore it to operational condition when a failure occurs). It has an important role in plant design. Optimum maintenance planning is a key operational factor. For maintenance analyses, the probability of performing a successful repair action within a given time is used. It is called *maintainability* and is expressed as a percentage. Reliability estimation is a useful tool to improve HEN design subject to uncertainties in the operating conditions. The efficiency was proved by Tellez et al. (2006). They analysed the design constraints for different possible variations of operating conditions. *Fault Tree Analysis* (FTA) of a coolant supply to heat exchanger was described by Lazor in the reliability handbook of Ireson et al. (1996) Although several approaches and methodologies have been studied in the field of heat exchanger and HEN fouling, RAM issues of HENs should be further studied to optimise HENs. Scheduled and unexpected shutdowns should be differentiated. The own characteristics of units should be considered. Important issues are the mean times between maintenance actions and the reduction of efficiency to certain levels. The *interaction between heat exchangers in the HEN* can be considered with the adequate application of software tools. Serial and parallel HENs, and the complex arrangements (block HENs) can be differentiated. *Main tasks to be optimised* are the appropriate scheduling of cleaning interventions of the individual exchangers in the HEN and the operating costs of the HEN. There are other tasks as the decision that should be made in each case individually for unit replacements at the right time to eliminate unnecessary shutdowns cased by unexpected faults (requires an estimation of current and future failure probabilities). *Analysing failures* is one of promising ways to determine availability and reliability issues of a system, including component failures, service failures, mechanical failures, operator errors, equipment failures. The important failure characteristics can be expressed by mean times. The widely used is the Mean Time Between Failures (MTBF). Further ones are the Mean Time Between/Before Repairs (MTBR) or the Mean Time To Failure (MTTF).

3. Applying software tools for HEN analyses

Maintenance requirements are different due to the wide variety of HENs and its operating conditions. There are specific requirements in each case. This complicates the good software choice which should these needs before starting the analyses. System reliability analysis consists of the decision of the *reliability approach* and the *reliability analyses* of heat exchangers within the HEN. The main steps are the following:

(i.) Gathering specific bundle failure history (data collection).
(ii.) Conduct Weibull analysis on the failure data.
(iii.) Failure probability calculations to estimate current probability of failure. The various operation classes of heat exchangers should be considered.

Both maintenance activities and failure mechanisms affect the way of conducting Weibull analysis. To control heat exchanger reliability, the probability of failure should be accurately predicted. Each tube lifetime is estimated from the installation date of the bundle to the failure date, at which time the failed tube is plugged. The reliability analysis of HENs can be performed manually or using software packages, which is a suggested approach as it has several advantages.

The main advantages of using RAMS software in HEN reliability modelling and optimisation can be summarized as follows: *Prediction of replacement times* can eliminate costs via failure analysis. Performing Weibull analysis on the failure data yields an estimation of MTBF and provides parameters that can be used to estimate future probability of failure. Based on Weibull parameters, it can be determined if exchangers in the HEN would probably be satisfactorily operational until the next scheduled outage. If not, what is more cost effective: to replace now or to wait for the next scheduled outage? Failure probability calculators are capable to *estimate current probability of failure*. The establishment of *new reliability culture* for plants can be introduced with RAMS software. System reliability can be improved. *Cost benefit analysis* can optimise the balance between maintenance costs and loss opportunity

costs. *Maintenance costs* have a potential reduction possibility through optimisation. *Loss opportunity costs can be reduced.*
RAMS software packages have various features. The variety of functions can be used through *cohesive modelling modules.* Typical examples are: system tree, FMEA table, fault tree table, LCC, Weibull tree, downtime distributions, parts table, prediction data, FMEA worksheet, maintainability data, maintenance policies, RBD, fault tree diagram, event tree diagram, Weibull graph. *Simultaneous analyses* can be used to handle RAM issues together. *Series and parallel subsystems can be combined.* HENs can be analysed by calculating the reliabilities of individual series and parallel sections and combining them. RAMS software offer a *wide variety of statistical distributions*.
RAMS software packages allow *total system approaches* in individual system component analyses. The different classes of scheduled maintenance can be considered, from total unit shutdown requirements to operation cutbacks by a certain percentage. All main groups of variables affecting fouling can be treated, including operational, maintenance, and scheduling variables. Maintenance costs can be significantly reduced by improving reliability, and achieve better economic performance at the same time.
The application of these software tools is a challenge to reliability engineers because there is a difference in the order of magnitude of time required for manual and for automated tasks. Data collection and entering them into reliability software take a few days or weeks while the time required for the software to perform predictions and calculations are typically from a few seconds to a few minutes, depending on the level of analyses and the types and amount of data to process – see the case study.

4. Demonstration through a case study

A HEN located in a petroleum refinery plant was selected for demonstration purposes. The details have been withdrawn for confidentiality purposes. The refinery had conventional crude preheat train which consists of a set of shell and tube heat exchangers. A complete RAMS analysis was performed. The analysed subsystem contained 36 heat exchangers and 2 desalters. The estimations and calculations were based on the failure data provided by the company. The failure data were inserted into the spreadsheets of Relex Reliability Studio. The Fault Tree Table had 8 types of component failures, 6 OR gates, and 15 basic events. The Fault Tree Diagram was generated based on the FTT (Fig. 2). Maintainability changes were tracked for the examined period (Table 1).
The time required to reach the desired level of maintainability was measured (Fig. 1). Inherent availability as well as system reliability were calculated. Weibull analysis and the estimation of future probability of failure were performed by Reliasoft Weibull++. The prediction of heat exchanger bundle replacement times provided by failure analysis outlined significant saving potentials. Several graphs were generated on logarithmic scales in SimuMatic, a Weibull++ extension, to emphasize the weak points. Based on the performed study, recommendations for improving the HEN maintenance and eliminate total unit shutdowns at the plant were provided. Scheduling of major outages could be improved while still considering costs. The frequency of supervisions would be beneficial. A threshold was recommended to set up to prevent very high fouling levels. The main maintainability problems were identified as the heat exchanger

failures, the schedule of cleaning interventions that are capable to reduce the effects of fouling, and the efficiency of repair actions.

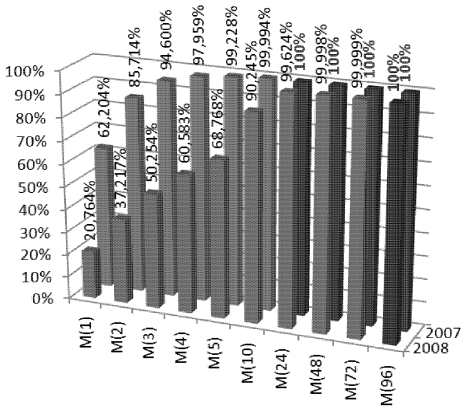

Figure 1. Maintainability results

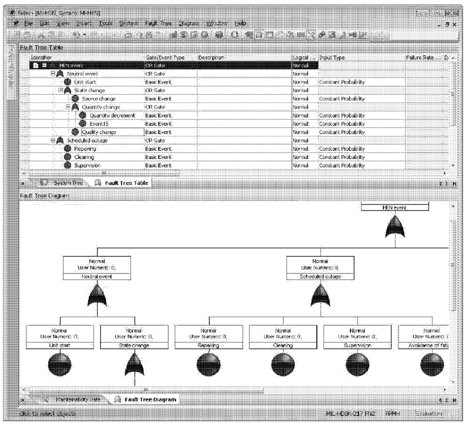

Figure 2. Fault tree diagram and fault tree table in Relex Reliability Studio

Table 1. Maintainability of the plant

Maintainability [h]	2007	2008
M(1)	62.204 %	20.764 %
M(2)	85.714 %	37.217 %
M(3)	94.600 %	50.254 %
M(4)	97.959 %	60.583 %
M(5)	99.228 %	68.768 %
M(10)	99.994 %	90.245 %
M(24)	100.000 %	99.624 %
M(48)	100.000 %	99.998 %
M(72)	100.000 %	99.999 %
M(96)	100.000 %	100.000 %

5. Conclusions

The proposed software modelling and optimisation methodology provides a way to reduce operational losses in HENs and reach these aims towards maintenance optimality. This approach is capable to reduce or even eliminate the need for total unit shutdowns required for cleaning. There are several advantageous features of reliability software that efficiently support to conducting complex analyses: Predictions performed through failure analysis are efficient to make suggestions to reduce or even eliminate unexpected faults in HENs. Reliability culture of plants or subsystems can be developed via total system approach, considering antecedent exchangers, HEN structure, local parameters, spares, and costs. Failure analysis contributes to the elimination of additional costs through the prediction of replacement times. Weibull analysis proved to be a good basis to determine if heat exchangers will probably survive until the next scheduled outage. Maintainability calculations in the case study outlined the probabilities of successful repair actions for given time periods, supporting the identification of additional requirements and equipment improvements.

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