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Reliability, availability and maintenance optimisation of heat exchanger networks

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ABSTRACT

A new methodology is proposed to use comprehensive up-to-date commercial software tools for heat exchanger network (HEN) reliability modelling and optimisation. The idea behind this proposal is that to apply the combination of specific HEN optimisation and reliability software packages has several advantages over the commonly used approach. There is a variety of features that need to be taken into account to choose the right software tool. The HEN design has a significant impact on reliability issues and this should be considered. There are many related issues and features – the robustness, the type of welding, the increment of maximum mechanical resistance, the impact on manufacturing costs, reduction of lost opportunity costs caused by exchanger outages, troubleshooting of heating exchanger problems by operators etc. Fouling should be analysed as it has a significant impact on maintenance issues. Up to 30% decrease of maintenance costs can be achieved annually by applying advanced reliability results and determining heat exchanger failure causes. These analyses include the investigation of failure causes, prediction of future probabilities of failures, cleaning planning and scheduling and the calculation of reliability and maintainability.

1. Introduction

Heat exchanger network is an important part of many processing and power generating plants. In most cases the HEN synthesis and design are assuming steady-state and non-variable operating conditions. In practice they can change and disturbances may occur.

Operational maintenance, availability and cost are some of the most important factors of HENs. All heat exchangers must be able to provide a specified heat transfer while maintaining a pressure drop across the exchanger. The propensity for fouling must be evaluated to assess the requirements for periodic cleaning. Fouling affects nearly every plant relying on heat exchangers for its operation. It is the accumulation of undesired solid material at the fluid or solid interface. Fouling introduces various costs, e.g. increased capital expenditure, and increased maintenance, loss of production, quality control problems, cleaning costs, additional hardware, and energy losses [1].

Fouling of individual heat exchangers has been the subject of intensive research in recent decades. However, HEN fouling has even more issues. Maintenance considerations in the scheduling of continuous and batch plants have recently received increasing attention. Muller-Steinhagen [2] proposed an integrated approach for developing alternative fouling mitigation strategies based on both experimental and modelling work. Georgiadis et al. considered the short term cleaning scheduling in special classes of HENs [3].

A wide variety of approaches are not limited to mathematical models and practical methodologies. The lifetime of heat exchangers varies with the application. A common practice to fouling mitigation is the implementation of cleaning-in-place (CIP) operations. Special heat exchangers exists which eliminate cleaning scheduling and maintenance activities by a self-cleaning mechanism. There are advanced materials, such as the hyper-duplex stainless steel, designed and developed to increase operating performance and to extend service life in severely corrosive heat exchanger applications.

Reliability estimation is a useful tool to improve HEN design subject to uncertainties in the operating conditions. The efficiency of the technique has been proved by Tellez et al. [4]. The analysis of the design constraints has been performed for different possible variations in the operating conditions.

Failure analysis contains fault tree analysis (FTA). An FTA of a coolant supply to heat exchanger has been described as an example by Lazor in the reliability handbook of Ireson et al. [5].

Although several approaches and methodologies have been studied in the field of heat exchanger and HEN fouling, reliability, availability, and maintenance (RAM) issues of HENs should be further studied, especially for optimisation purposes. Scheduled and unexpected shutdowns should be differentiated. Maintenance times should be optimised. The characteristics of units should be

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Nomenclature

Acronyms

CAD	computer aided design
CFD	computational fluid dynamics
CIP	cleaning-in-place
CPT	crude preheat train
FA	failure analysis
FLES	Fuzzy-logic expert systems
FMEA	failure modes and effects analysis
FTA	fault tree analysis
HE	heat exchanger
HEN	heat exchanger network
LCC	life cycle cost
RAM	reliability, availability, and maintenance
RAMS	reliability, availability, maintainability, and safety
RBD	reliability block diagram
RCA	root cause analysis

Quantities

A_i	inherent availability (%)
A_o	operational availability (%)
M	maintainability (%)
$M(x)$	time fraction of maintainability (%)
t_{MC}	mean cycle time (h)
t_{MD}	mean downtime (h)
t_{MTBF}	mean time between failures (h)
t_{MTBMA}	mean time between (or before) maintenance actions (h)
t_{MTBR}	mean time between (or before) repairs (h)
t_{MTTF}	mean time to failure (h)
t_{MTTFF}	mean time to first failure (h)
t_{MTTR}	mean time to repair (h)
t_{MU}	mean uptime (h)
Q	unreliability (%)
R	reliability (%)
t	time duration analysed (h)
t_{TD}	total downtime (h)
t_{TU}	total uptime (h)
U_i	unavailability (%)

Greek symbols

β	Weibull shape parameter (slope)
ΔT	temperature difference (°C)
η	Weibull scale parameter
θ	mean time between failures (*MTBF*) (h/failure)
λ	failure rate (1/h)
μ	repair rate (1/h)

considered. Another important issue is the mean time between maintenance and the reduction of efficiency to certain levels.

Present paper focuses on the possibilities of advanced software tools that support this field. The paper introduces a methodology for effective modelling and optimisation of HEN maintenance and reliability.

2. Problem statement

Market pressures drive management to achieve higher and higher levels of availability and reliability. However, the motivation to improve reliability is more complex than simply to reduce maintenance costs. There is a need to control reliability for best economic performance. In fact, least cost maintenance is not recommended when a plant strives to achieve high reliability. Maintenance costs are relatively low when compared with loss opportunity costs. HEN reliability issues can be effectively handled with RAMS software. The reliability issues of HENs deserve much more attention. Most designers mainly focus on HEN capital and operation cost optimisation only. The reliability issues of HENs should be properly analysed and improved by relevant software tools. All relevant features affecting availability, reliability and maintenance should be considered while modelling and optimising HENs. One of these factors is the interaction between heat exchangers in the HEN. The main task of optimisation is the *appropriate scheduling of cleaning interventions* of the individual exchangers in the HEN. It can be based on a priori knowledge of the time behaviour of the thermal resistance of fouling [6]. Further tasks to be optimised are the *operating costs* of the HEN. The estimation of current and future failure probabilities are required to make the decision for equipment replacements performed at the right time to eliminate unnecessary shutdowns cased by unexpected faults. The simple cases, including series and parallel HENs, and the complex arrangements (block HENs) should be differentiated as their fouling factors are different. The detrimental effect of fouling can be reduced by adopting appropriate measures in HEN design [7]. Important is the *choice of local parameters* and the *HEN structure* [8].

Enhancing heat exchanger reliability has many advantages. Cost effectiveness can be increased; plant assets management can be improved. Component lifetime can be extended, and leakages can be detected prior to shutdown. Improved reliability results in reduced maintenance costs and a better economic performance.

2.1. RAM of heat exchanger networks

Reliability is the probability that the HEN will perform satisfactorily for at least a given period of time when used under certain conditions [5].

The *availability* of a heat exchanger network represents the capability to manage heat and power streams continuously in a usual and regular way. The cause of failures varies, including mechanical failures, corrosion, fouling, and sealing problems.

Maintenance has an important role in plant design. *Optimum maintenance planning* is a key factor in modern HENs. Maintenance covers the activities undertaken to keep the HEN operational (or restore it to operational condition when a failure occurs).

A measure of difficulty and speed with which a system can be restored to operational status after a failure occurs can be expressed *maintainability*, i.e. the probability of performing a successful repair action within a given time.

Analysing failures is an important way to determine availability and reliability issues of a system, including component failures, service failures, mechanical failures, control system failures (or malfunction), the failures to detect faults, changeover failures, lack of manpower, operator errors, and instrument failures.

The most important failure characteristics can be expressed by *mean times*. The widely used is the *mean time between failures* (MTBF), i.e. the reciprocal of failure rate. Further types of mean times are the *mean time before maintenance actions* (MTBMA), the *mean time between repairs* (MTBR), and the *mean time to failure* (MTTF).

Two types of *fouling-induced effects should be identified* in HENs [7]:

(i) Changes in outlet temperature of process streams caused by the thermal resistance of fouling in an exchanger.