CHEMICAL ENGINEERING TRANSACTIONS
VOL. 33, 2013
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at: www.aidic.it/cet
Guest Editors: Enrico Zio, Piero Baraldi
Copyright © 2013, AIDIC Servizi S.r.l.,
ISBN 978-88-95608-24-2; **ISSN** 1974-9791
DOI: 10.3303/CET1333062

Data Field for Decision Making in Maintenance Optimization: An Opportunity for Energy Saving

Behnoush Darabnia*, Micaela Demichela

SAfeR- Centre of Studies on Safety, Reliability and Risks, DISAT- Department of Applied Science and Technology
Politecnico di Torino, Corso Duca degli Abruzzi, 24,10129 Torino, Italy
behnoush.darabnia@polito.it

Energy saving is an important issue for the industrial sectors which is a crucial factor in energy cost, waste reduction and environmental management. Maintenance operations are fundamental in granting machineries and processes energy saving, given the capability of optimising them thanks to a predictive model. The major challenge of maintenance optimization is to implement a maintenance strategy, which maximizes availability and efficiency of the equipment, controls the rate of equipment deterioration, ensures the safe and environmentally friendly operation, and minimizes the total cost of the operation which means the both production and energy cost. To ensure that the plant achieved the desired performance it needs a track performance on maintenance operations and maintenance results. In addition it needs the relationship between the inputs of the maintenance process and the outcomes in terms of total contribution to manufacturing performance and objectives. In addition to normal wear and deterioration, other failures may occur especially when the equipment are pushed beyond their design limits or due to operational errors. As a result, equipment downtime, quality problems, energy losses, safety hazards or environmental pollution become the obvious outcomes. All these outcomes have the potential to impact negatively the operating cost, profitability, customers' demand satisfaction, and productivity among other important performance requirements.
The developed model in this study is an integration of a probabilistic and a deterministic model based on balanced cost and benefits, able to support decision making. This is described through the application to a case study: the optimisation of maintenance operations in energy consuming equipment in the production process of bituminous materials, based on the energy audit from the field and a part of the results are illustrated in this work.

1. Introduction

In grate energy consuming industries such as cement, iron and steel, pulp and paper and chemistry are practiced and applied many different Energy Efficiency technologies and measures which are consist of improving purchasing, maintenance practices and procedures. These measures often have positive implications other than just energy savings. They can also reduce maintenance costs and increase the productivity benefits of the site, and vice versa. Maintenance management is defined as all the activities of the management or priorities (availability, cost reduction), strategies; such as management method in order to achieve maintenance objectives, and responsibilities, and implement them by means such as maintenance planning, maintenance control and supervision, and several improving methods, including economic aspects in the organization, which was discussed by (Crespo and Gupta, 2006). Maintenance objectives can be summarized under five headings: (i) ensuring the plant functionality (availability, reliability, product quality etc.); (ii) ensuring the plant achieves its design life; (iii) ensuring plant and environmental safety; (iv) ensuring cost effectiveness in maintenance and (v) effective use of resources, energy and raw materials.
Reliability, availability, maintainability and safety are the key indicators of maintenance efficiency, which are critical in optimizing maintenance model, and were recently discussed by (Qingfeng et al., 2011). As an example; industrial compressed air systems require periodic maintenance to operate at peak efficiency

Please cite this article as: Darabnia B., Demichela M., 2013, Data field for decision making in maintenance optimization: an opportunity for energy saving, Chemical Engineering Transactions, 33, 367-372 DOI: 10.3303/CET1333062

and minimize unscheduled downtime. Inadequate maintenance can increase energy consumption via lower compression efficiency, air leakage, or pressure variability. It also can lead to high operating temperatures, poor moisture control, excessive contamination, and unsafe working environments. Most issues are minor and can be corrected with simple adjustments, cleaning, part replacement, or elimination of adverse conditions which means preventive maintenance.

2. Maintenance decision making

Maintenance activity, its costs and its effectiveness in any type of system depends on the correct integration of four main types of maintenance which are reactive, preventive, predictive and proactive or ameliorative. The decision-making procedure allows the selection of an optimum set of maintenance procedures. Maintenance decision making can be broadly explained in terms of maintenance actions (basic elementary work), maintenance policies and maintenance concepts. Inspection and maintenance planning based on risk analysis minimizes the probability of system failure and its consequences. It helps management in making correct decisions concerning investment in maintenance and related fields. Although the decision-making procedure allows the selection of a set of maintenance practices to be used in equipment, it does not indicate the selection of the most cost effective maintenance practice. So as to deal with this issue, one needs to evaluate the equipment failure probability and the costs of maintenance and failure consequences. The methodology proposed, for maintenance policy selection is presented in Figure 1 that was illustrated by (Carazas and Souza, 2010).

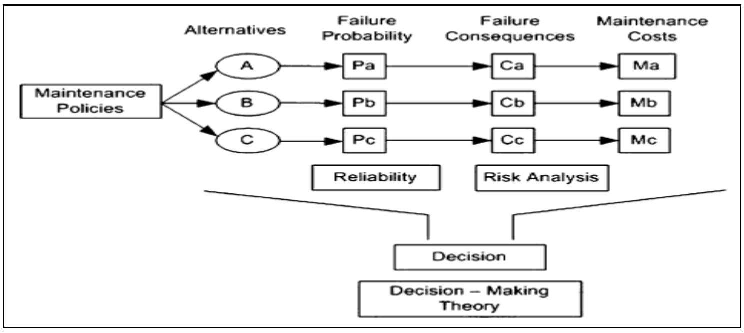

Figure 1. Flowchart for decision making risk base methodology.

Initially, the maintenance planner must list all possible maintenance procedures that present technical feasibility, to be applied to the equipment. For each one of those maintenance procedures, the equipment failure probability must be evaluated through the use of reliability concepts. Based on "time to failure" database, the analyst can calculate the equipment reliability. The second step in the procedure is the assessment of maintenance procedures costs and equipment failure consequence costs based on cost database. The equipment failure consequences costs assessment involves the definition of the equipment failure effects on the plant operational availability and safety, including environmental impact.
The risk analysis concepts are usually used to predict the equipment failure consequences given an industrial plant operational scenario. Once the equipment failure probability is evaluated for each of the feasible maintenance procedures, the failure consequences and maintenance costs are estimated, a decision-making procedure, based on decision tree, can be used to select the maintenance procedure that minimizes the risk associated with the equipment failure expressed by the mean failure costs.
That must be mentioned, most engineering, maintenance and operating decisions involve some aspect of cost/risk (inefficiency) trade-off. Such decisions range from evaluating a proposed design change determining the optimal maintenance or inspection interval, when to replace an ageing asset, or which and how many spares to hold. The decisions involve deliberate expenditure in order to achieve some hoped-for reliability, performance or other benefit.

3. Cost effective energy saving by maintenance optimization

The importance of the cost effective energy saving measures in industry facilities is to reduce energy consumption of major energy using equipments. Cost minimization is also one of the objectives of maintenance planning. Over the recent decades plant maintenance strategies have evolved from corrective to the preventive approach and deterministic models have been integrated or replaced by those based on reliability and risk, which are probabilistic. Approaches to obtain the optimum maintenance

interval bring to minimization of total cost. On the other hand the aim of these approaches is to achieve productivity and cost benefits in industries. Even if their purpose is not directly energy related, their benefits often are applied also to energy saving. For example, the most common cost benefits of improved maintenance and operation system is achieved from reduced equipment wear and tear.
For quantifying the impact of maintenance and productivity benefits on energy saving, it is possible to calculate the Cost of Conserving Energy CCE, which is shown by Eq. (1) and (2). CCE also includes the 'non-energy benefits' like maintenance and operation system optimization, which was also discussed by (McKane and Hasanbeigi, 2011).

$$CCE = \frac{I.q + M\&O}{S} \tag{1}$$

$$q = \frac{d}{(1-(1+d)^{-n})} \tag{2}$$

Where, CCE is the cost of conserved energy for the energy efficiency measure in €/kWh, I is the capital cost in €, q is the capital recovery factor, M&O is the annual change in Maintenance and Operation costs in €/y, S is the annual energy saving in kWh/y, d is the discount rate and n is the lifetime of the conservation measure, in y.
It should be noted that non-energy benefits, as operation system and maintenance optimization lead to reduction in M&O, as well as reduction of capital cost, that would lead to reduction in I, with a higher effects on CCE.
In our study, the real discount rate d was assumed equal to 0.75% per y, to reflect the barriers to energy efficiency investment in industry such as: perceived risk, lack of information, management concerns about production and other issues, capital constraints, and preference for short payback periods about 3 y.
The cost analysis is dependent on the existence of a database that relates costs to some undesirable failure events associated with process plant equipment. For the present analysis, the costs are divided into three classes: (i) Fixed operational costs; (ii) Variable operational costs, and (iii) Unavailability costs, which also were discussed by (Muchiri et al., 2011). The total maintenance and operational costs can be calculated by the sum of those costs, as shown in Eq. (3) below:

$$Total\ M\&O\ cost = Fixed\ cost + Variable\ cost + Un\ availability\ cost \tag{3}$$

The Maintenance and Operation fixed costs are related to the process plant operation independently. Those costs include plant operator's wages, general and equipment maintenance costs (for procedures that do not depend on the equipment operation time history), insurance and taxes. The variable M&O include costs that are dependent on the amount of production or on the equipment operation time history. Both classes of costs are dependent on the maintenance policy applied on the process plant equipment.

4. Data field for decision making

The decision making model and data analysing are shown through application to a case study in an industrial production process in Bitumtec Ltd. plant, which produces bituminous materials for road paving.
Here was chosen the batch production process of modified bitumen. They produce maximum 20-21 t/h modified bitumen. For this process, they possess two mixers which alternate with each other annually. Polymer, chemical additives and bitumen enter in the primary mixer and recycled for many times that depends on the quality of the product and in the end of the process for the last time the mixture passes in to the secondary mixer where exits modified bitumen which has high quality and performances.
Energy efficiency analysis developed model was used to estimate the potential cost-effectiveness of electrical efficiency for the motor system (as an example) or the most critical component which is the great energy consumer. The motor is used during production and drag the mill which homogenized the polymer.
The proposed framework with flowing steps are introduced:

- Identification of the most critical system MCS

Particularly, in this work was addressed the electrical three phases motor (160 kWh).

- Life time and energy consumption data collection and observation, also related maintenance activities (corrective and preventive) and failures data collection.
- Estimated costs of maintenance and the economic evaluation of maintenance policies, based on balanced cost and risk of inefficiency.
- Maintenance optimization, in terms of probability and consequences.
- Estimated operating costs of the system.

• Analysis of energy efficiency through maintenance optimization and operating procedures, by using of bottom-up energy efficiency supply curve model, where it was introduced:
Expert inputs (based on the information of the expert of the system), and data assumption.
• Definition of scenarios and efficiency measures; here was defined three levels of potential for recovery of electricity: low, medium and high also proposed solutions to increase the efficiency based on the maintenance activities, operating procedures and the conditions of the system.
• Determination of the impact of these measures on the performance.
To determining the impact of the energy efficiency measures, the expert of the system was asked to provide his opinion on energy savings likely to result from implementation of each measure expressed as a % improvement for each of the Low, Medium and High base cases. The percentage efficiency improvement by the implementation of each measure decreases as the base case moves from Low to High. Here by using our developed model, are estimated annual saved energy and annual potential of CO_2 reduction for any efficiency level, as is shown by Table 1.

Table 1: Cost-effectiveness and environmental benefits estimated for each base scenario.

Efficiency base case scenarios	Characteristics	Potential recovery efficiency %	Average annual energy consumption kWh	Average energy price €/kWh	q	Annual saved energy kWh/y	Annual potential CO_2 reduction $kgCO_2/y$
Low	Maintenance is limited to what is required to support operation	15	300000	0.15	0.922	45000	22500
Med.	Maintenance is a routine part of operations and includes some preventive actions	10	300000	0.15	0.922	30000	15000
High	Both routine and predictive maintenance are commonly practiced	5	300000	0.15	0.922	15000	7500

That must be noted, studying the historical data has been noted that the old motor has broken after 8000 h working, on July 2010, fortunatley they had also a new motor in the stock, so they have had only 10 hours of stop working and loss of production (time to remove old motor and instal the new one). Therfore, in 2010, the motor system in addition to predictive (ordinary) maintenance also has had corrective maintenance. It was also estimated CCE for each three base case scenarios. In the Figure 2, is shown estimated cost of conserved energy for the motor system for each bese case efficiency for the years 2010, 2011 and 2012.

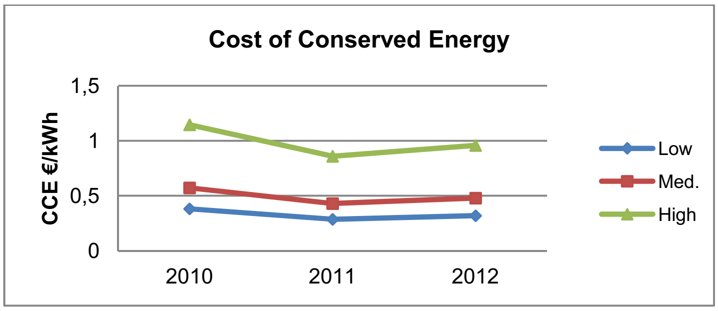

Figure 2. Cost of conserved energy €/kWh.

Decision making was made in the base of efficiency level, therefore were established and proposed solutions to increase the efficiency based on the maintenance activities, operating procedures and the conditions of the system, here also were estimated through our developed model, cunmmulative annual energy saving and cumulative annual potential of CO_2 reduction for a medium level base case scenario which are showed byTable 2.

Table 2: Energy efficiency measures for the motor system (case study).

Energy efficiency measures for motor system	Base case efficiency scenarios: Low (Up to15%)	Med. (Up to 10%)	High (Up to 15%)	Cumulative annual energy saving kWh/y	Cumulative annual potential CO_2 reduction $kgCO_2/y$
	Possibility of energy recovery %			For Med. level	For Med. level
Upgrade system maintenance					
1. Fix leaks, damaged seals and packing	3.0	2.0	1.0	4.696	2.348
2. Remove sediments from mixer	7.0	5.0	3.0	15.668	7.834
3. Replace Motor with more energy efficient type	14.0	7.0	5.0	29.413	14.706
4. Use of new technologies and more efficient devices, like: New belts(higher power transition and maintenance free)	1.0	1.0	1.0	31.240	15.620
5. Initiate predictive maintenance program (maintenance optimization)	7.0	5.0	2.0	39.917	19.959
6. Use of inverter (o Variable speed drive)	*not economical convenient for the case study.			43.189	21.595

*Management consumption of the motor, to minimize peaks during start of the work is economic alternative for measure 6, by starting motor only one time a day, and turned off motor only at the end of the daily work.

Figure 3 shows the conservation supply curve for the electric motor system (case study), that presents the energy saving potential as a function of the marginal CCE, which accounts for the costs associated with implementing of each measure (Table 2) that includes maintenance and operation costs M&O.

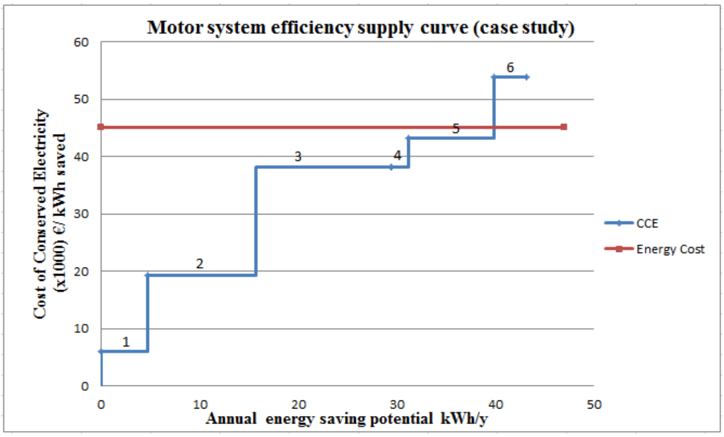

Figure 3.The conservation supply curve for electric motor system (case study).

It should be emphasized, our industrial case study was in the medium base case scienario. The implementation of energy saving measures, for our case study was based on both technical and economic feasibility. The energy efficiency measures that are below the energy cost line (here annual electrical energy cost is about 45000€), are both technical and economic feasible so are cost-effective and the efficiency measures that are above the energy cost line are not cost effective, so in this study measure 6 technically is possible, but is not economic. Results have also demonstrated that even only through maintenance optimization, it is possible to increase the performance of the system up to 10%, for a medium base case scenario, as is shown in Figure 4.

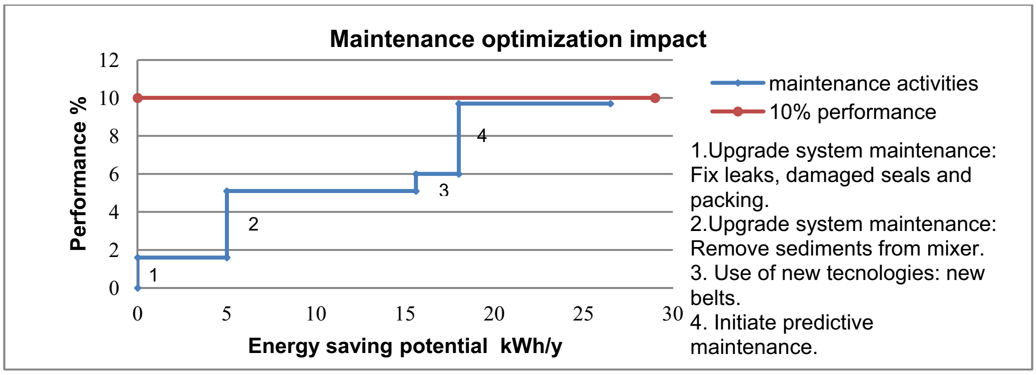

Figure 4. Maintenance optimization impacts (case study).

5. Conclusion

Analysis has been emphasized, the importance of optimizing maintenance activities to increase the performance of the system. Using developed efficiency analysis model, it is possible to quantify the impact of maintenance and operating procedures, in terms of energy savings or cost-effectiveness, and can be calculate the cost of conserved energy, also it is possible to estimate the potential reduction of greenhouse gas emissions (CO_2). In this work, energy efficiency was evaluated for three different base case scenarios; low, medium and high with relative potential energy recovery, also was estimated their relative performance and environmental benefits. It must be emphasized, maximizing efficiency of the system or our goal is achieved through the use of efficiency model, which also based on analysis of historical data, expert inputs and analysis of the economic impacts. However, thanks to the cooperation by the company, the analysis and the results were validated and compared by the experts of the system, which a part of the results were illustrated in this work.

Acronyms

CCE Cost of conserving energy, €/kWh
d Discount rate
I Capital cost, €
M&O Annual change in Maintenance and Operation costs, €/y
n lifetime of the conservation measure, y
q Capital recovery factor
S Annual energy saving, kWh/y

References

Carazas F.G., Souza G.F.M., 2010, Risk-based decision making method for maintenance policy selection of thermal power plant equipment, Energy, 3, 964-975.
Crespo M.A., Gupta J.N.D., 2006, Contemporary maintenance management: process, framework and supporting pillars, The International Journal of Management Science Omega, 34, 313-326.
McKane A., Hasanbeigi A., 2011, Motor systems energy efficiency supply curves: A methodology for assesing the energy efficiency potential of industrial motor systems, Energy Policy, 39, 6595-6607.
Muchiri P., Pintelton I., Gelders L., Martin H., 2011, Development of maintenance function performance measurement framework and indicators, International Journal of Production Economics, 131, 295-302.
Qingfeng W., Wenbin L., Xin Z., Jianfeng, Y., Quingbin Y., 2011, Development and application of equipment maintenance and safety integrity management system, Journal of Loss Prevention in the Process Industries, 24, 321-332.