CHEMICAL ENGINEERING TRANSACTIONS
VOL. 70, 2018
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Guest Editors: Timothy G. Walmsley, Petar S. Varbanov, Rongxin Su, Jiří J. Klemeš
Copyright © 2018, AIDIC Servizi S.r.l.
ISBN 978-88-95608-67-9; **ISSN** 2283-9216
DOI: 10.3303/CET1870130

Asset Management for Energy System Retrofit

Petar Sabev Varbanov[a,*], Timothy Gordon Walmsley[a], Jiří Jaromír Klemeš[a], Andreja Nemet[b], Zdravko Kravanja[b]

[a]Sustainable Process Integration Laboratory – SPIL, NETME Centre, Faculty of Mechanical Engineering, Brno University of Technology - VUT, Brno, Czech Republic
[b]Faculty of Chemistry and Chemical Engineering, University of Maribor, Slovenia
varbanov@fme.vutbr.cz

Energy System Retrofit is an important activity for simultaneously improving resource efficiency, economic performance and contribution of industry to sustainability. While identifying thermodynamically and technically feasible options for retrofit-based energy savings is an important necessary step, it is not a sufficient one for achieving real savings. A further necessary step is the selection of a set of economically feasible and attractive ways of implementing the identified retrofit options. This paper provides an analysis of the investment planning concepts as applied to the retrofit of Heat Exchanger Networks (HENs) and identifies the key issues for retrofit implementation and planning. The paper concludes with the formulation of further research goals, aimed at the establishment of an integrated method for optimal planning of retrofit investments in energy systems.

1. Introduction

For Heat Exchanger Networks (HENs), retrofit actions may involve enhancing existing heat exchangers by inserts or additional heat transfer area, moving them within the network, or adding new ones. Often the identified retrofit plans involve investment exceeding the available funds (Novak-Pintaric and Kravanja, 2007) or making necessary loan intake. In such a situation, company managers need to construct an investment plan, selecting only a sub-set of retrofit actions or devising several campaigns, each fitting an assigned investment limit.
HEN retrofit has been investigated systematically first by Tjoe and Linnhoff (1986), eliminating Cross-Pinch heat exchangers. The further development includes the Network Pinch method (Asante and Zhu, 1996), considering varying heat exchanger types (Soršak and Kravanja, 2004) or heat transfer intensification (Pan et al., 2012). Other HEN representation tools have been devised for analysing their performance and facilitating retrofit – including the Shifted Retrofit Thermodynamic Diagram (Yong et al., 2015), Energy Transfer Diagram (Bonhivers et al., 2017), Retrofit Tracing Grid Diagram (Nemet et al., 2015). Those works help in identifying and costing retrofit actions, maximising the energy savings and/or minimising the payback time of the retrofit investment.
Novak-Pintaric and Kravanja (2007) presented a MINLP model, for stage-wise implementation of HEN retrofits. The considered retrofit actions focus on adding recovery heat exchangers. Energy sector-wide investment planning has been investigated in (Flores et al., 2015), accounting for economic and environmental performance. Jackson and Grossmann (2002) addressed the retrofit of a general process network within a single investment campaign, by maximising the economic potential of the resulting network over a specified time horizon. Menezes et al. (2015) have presented a capital investment model for oil refineries. The modification actions are classified into maintenance, tactical and strategic. While they provide certain insights into the scheduling of the process modifications, the focus of the treatment is mainly on refinery capacity expansion and key properties of the process equipment (assets) are not considered. For example, the physical (e.g. remaining lifespan) and financial (e.g. level of depreciation) statuses of the process equipment units are left out.
While many aspects of retrofit planning have been covered separately, the area clearly needs to be further developed, allowing for an appropriate conceptual base in asset management and investment planning. The open issues include equipment and system models tracking the condition, performance, reliability and financial properties. This contribution investigates the properties of retrofit and investment plans, then formulates the necessary concepts, mathematical representation and visualisation tools.

Please cite this article as: Varbanov P.S., Walmsley T.G., Klemes J.J., Nemet A., Kravanja Z., 2018, Asset management for energy system retrofit , Chemical Engineering Transactions, 70, 775-780 DOI:10.3303/CET1870130

2. Modelling concepts

From the viewpoint of investments, it is necessary to present the outcome from retrofit actions in a suitable format. The most popular investment project representation is the discounted cash flow model, using the projected Net Present Value (NPV) to judge its economic attractiveness. This implies evaluating the financial performance of the system in a series of annual time slices on the Equipment Planning Grid developed in this work (Figure 1) for a specified Planning Horizon (PH). For each annual time slice, key properties of the underlying plant (HEN) are tracked and estimated:

- Remaining Service Life (RSL)
- Book Value (BV) – part of the equipment cost pending to be written off via adding to the current expenses; Scrap Value (SV), also known as “Salvage Value” (Green and Perry, 2008) – the amount of money that can be retrieved by selling the equipment item at the end of its service life.
- Annual Expense (AE), comprising the Operating Cost (OC) and Annual Depreciation (AD).

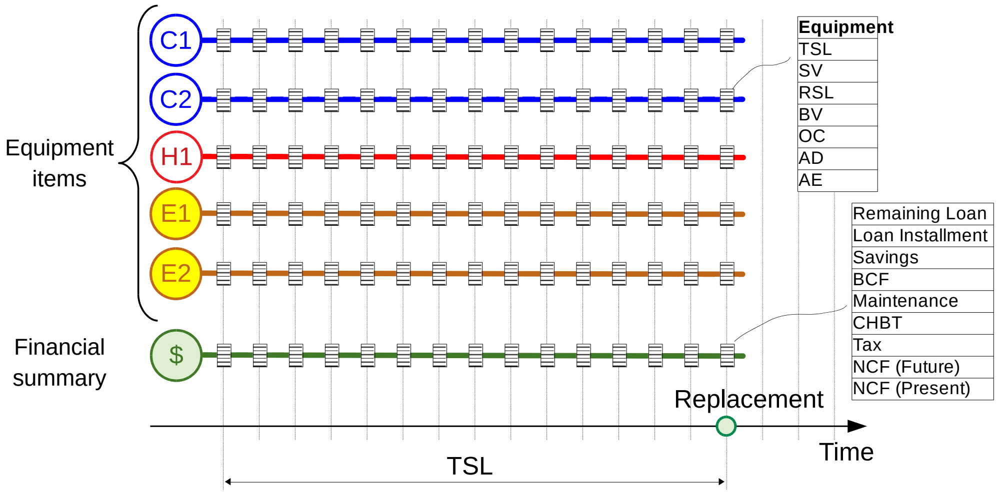


Figure 1: Assets – Equipment Planning Grid

The PH duration can be set depending on different considerations. Possible durations can be the Total Service Life (TSL) of equipment added to an existing plant, or the TSL of a newly erected plant. For revealing the key interactions in asset management for HEN retrofits, in this paper the PH is set to a longer period, spanning several cycles of equipment replacement for revealing the trends of the HEN performance over the cycles and illustrates the potential overlaps and interactions between the existing and the added parts of the HEN.

The existing system performance in terms of energy and economy is taken as a baseline. All cost, revenues and profits are considered as part of the base design and management of the plant. The performance of the existing network is evaluated only to the extent necessary for making the link to the potential retrofit options. The book value, cost, and expenses for the HEN are evaluated for the specified PH.

For an equipment item added during the retrofit, the tracked properties are the same as for existing equipment. However, for retrofit project evaluation, the existing equipment would have served already for some time. at the beginning of the evaluation of the retrofit project (Year 0), existing items would have certain age and RSL would be shorter than TSL. For the added equipment RSL = TSL. The eventual loan intake refers only to the retrofitted part of the system. Any existing investments and loans prior to the considered retrofit action are assumed to be parts of separate investment projects.

Scrap Value is not discounted. The equipment depreciation period is assumed identical with TSL. The Annual Depreciation (AD) of an equipment item is calculated using the linear method (Green and Perry, 2008). For the last year of the equipment life, the depreciation is equal to the scrap value.

Referring to Figure 1, the financial properties of the retrofit project for each time slice are evaluated as follows:

(1) Loan intake and remaining loan are calculated by taking the sum of the investment and subtracting available cash reserves (if any) and the scrap value from selling previously used equipment.
(2) Loan repayment instalments are calculated using a compounding rule based on the loan interest rate. It is assumed that the period for loan repayment is equal to TSL.
(3) The financial savings from the retrofit actions (for HEN from reduced utility demand) are estimated.
(4) From the savings, certain expenses are subtracted: those for loan repayment, maintenance and taxes.
(5) Performance indicators are estimated: NPV, overall expenses, BV, RSL

3. Case Study

The illustration case study has been derived from the HEN example in (Walmsley et al., 2017). The existing HEN is shown in Figure 2. The planning is set to PH = 40 y. The operating, investment and maintenance costs, as well as the loan intake and repayment, have been compounded using the financial parameters from Table 1. The installed cost (IC) of a heat exchanger is calculated according to Eq(1) (Isafiade et al., 2017).

$$IC = 13{,}000 + 4{,}333 \times Area^{0.6} \tag{1}$$

In Table 1, the Capital Inflation Rate is used for investments and for maintenance costs (because the latter are linked to the installed capital). It is assumed that the investors expect the level of returns equal to or higher the loan interest rate. The maintenance cost is estimated as a fraction of the Installed Cost (Smith, 2016). In Table 1 the inflation rates for capital and for utilities are different. This reflects previous studies that utility cost grows noticeably faster than capital cost (Morrison et al., 2012). For all equipment, items are assumed TSL = 15 y. The Scrap Value (SV) of equipment items is assumed to be 4 % of the Installed Cost (Table 1).

Table 1: Financial parameters of the case study

	T_{start}, °C	T_{end}, °C	Price* \$/(kW × y)
Steam price***	250.1	250.0	100
CW price***	15.0	20.0	10
Utility Inflation Rate	(1/y)	0.03	
Capital Inflation Rate	(1/y)	0.01	
Loan Interest Rate (LIR)	(1/y)	0.04	
Investor Discount Rate	(1/y)	0.04	
Maintenance cost rate**	(1/y)	0.05	
Scrap Value Share	(1)	0.04	
Corporate tax rate	(1/y)	0.15	

* At the beginning of the consideration (Year 0)
** Smith (2016); *** (Isafiade et al., 2017)

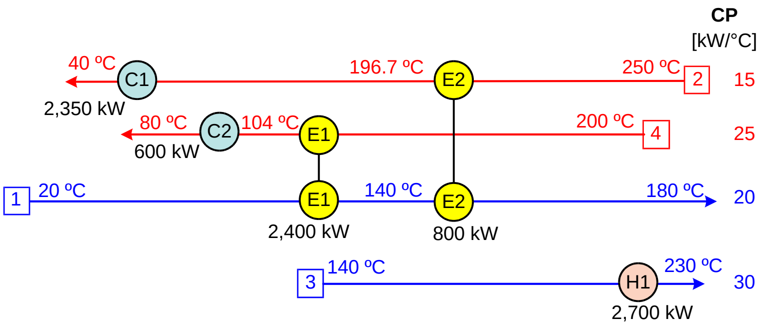


Figure 2: Initial HEN

The retrofit for heat recovery improvement is evaluated on the 5th year of the plant life. Table 2 shows the calculated heat exchanger properties. Two retrofit options are considered (Walmsley et al., 2017):

(1) Adding heat exchangers E3 and E4, thus implementing a bridge that connects cooler C1 with heater H1 (Figure 3). This retrofit action is also referred to as “Step 1”.

(2) A combination of Step 1 with adding heat exchanger E5 (Step 2). This option generates a maximum heat recovery network (Figure 4).

Option 1, besides adding E3 and E4, also results in the need for an increased heat transfer area for E1. Since the additional size is significant (Table 3), it is implemented as a new equipment item. The implementation of the additional area for E1 and E2 for Option 2 (Table 4) is similarly implemented by new equipment items. Tables 3 and 4 list the calculation results for the two retrofit options. Together Tables 2-4 provide the heat exchanger sizes necessary to achieve the required duties. The investment cost-related data refer to the beginning of the evaluation (Year 1).

Assuming that all investment for the retrofit comes from a bank loan sets the initial investment by shareholders to zero. In this case, the loan is paid back to the bank in fixed instalments, calculated by accounting for interest accumulation (Brown, 2018):

$$Installment = \frac{LIR \times Loan}{1-(1+LIR)^{-TSL}} \quad (2)$$

Table 2: Area and cost properties of the existing HEN

HE	Duty kW	U kW/(m²×°C)	Area m²	IC* $	SV* $	AD* $/y
C1	2,350	0.40	75.74	71,130	2,845	4,552
C2	600	0.40	20.24	39,337	1,573	2,518
H1	2,700	0.90	56.72	61,870	2,475	3,960
E1	2,400	0.45	74.77	70,681	2,827	4,524
E2	800	0.48	26.41	43,890	1,756	2,809
Total utility cost ($/y): 299,500						

U: Overall heat transfer coefficient; AD: Annual Depreciation
* At the beginning of the consideration (Year 0)

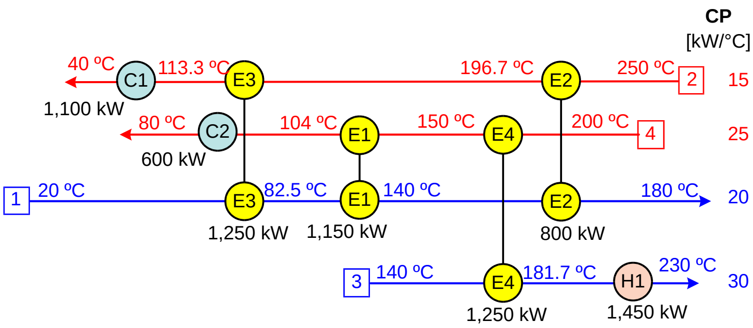


Figure 3: HEN for Option 1: Adding exchangers E3 and E4 (Step 1)

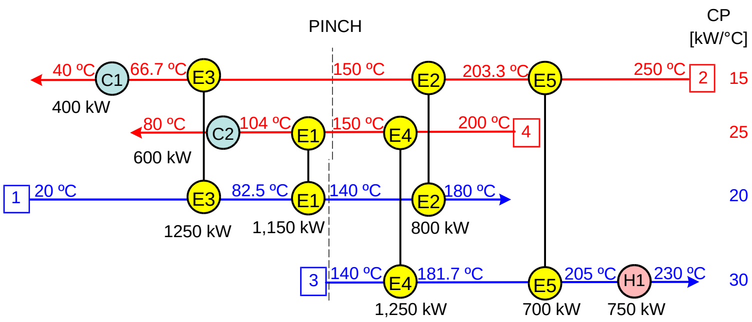


Figure 4: Adding exchanger E5 (Steps 1 and 2 – Maximum Energy Recovery)

Table 3: Area and cost properties for Option 1: Adding exchangers E3 and E4 (Step 1)

HE	Duty kW	U kW/(m²×°C)	Added Area m²	IC* $	SV* $	AD* $/y
New heat exchangers						
E3	1,250	0.48	25.19	43,025	1,721	2,754
E4	1,250	0.46	197.85	116,417	4,657	7,451
New area of existing heat exchangers						
E1	1,150	0.45	95.33	79,732	3,189	5,103
Total utility cost ($/y): 162,000				Savings ($/y): 137,500		

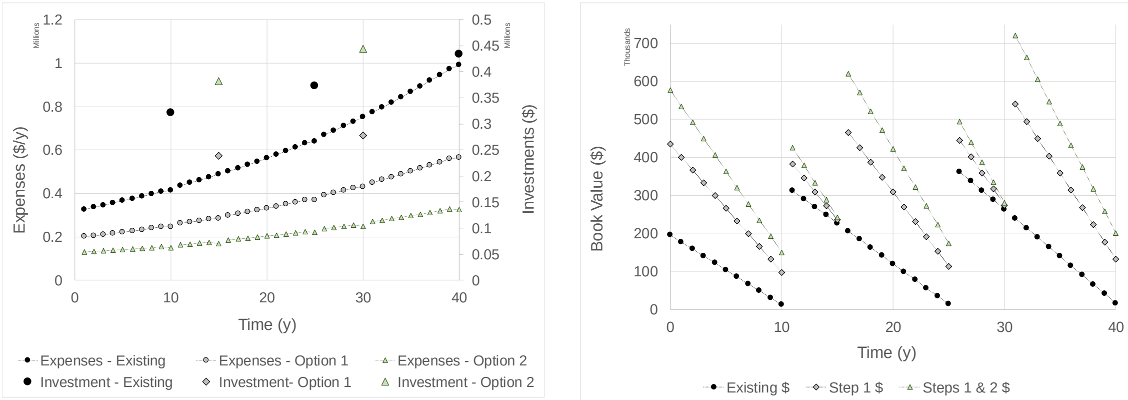
*At the beginning of the consideration (Year 0)

As a result, for PH = 40 y, the trends for expenses, investments and BV have been obtained, complemented with the following NPV values: Option 1: $ 3,154,790; Option 2: $ 4,908,657.

Table 4: Area and cost properties for Option 2: Implementing both Steps 1 and 2

HE	Duty kW	U kW/(m²×°C)	Added Area m²	IC* $	SV* $	AD* $/y
New heat exchangers						
E3 (Step 1)	1,250	0.48	46.12	56,165	2,247	3,595
E4 (Step 1)	1,250	0.46	197.85	116,417	4,657	7,451
E5 (Step 2)	700	0.46	47.73	57,063	2,283	3,652
New area of existing heat exchangers						
E1	1,150	0.45	95.33	79,732	3,189	5,103
E2	800	0.48	79.59	72,884	2,915	4,665
Total utility cost ($/y): 85,000				Savings ($/y): 214,500		

*At the beginning of the consideration (Year 0)



(a) Expenses and Investments (b) Book Value

Figure 5: Financial properties of the retrofit options

Both options are profitable. However, Option 2 seems a little less economically attractive. For the correct quantification of the profitability of the two options, it is necessary to calculate the Internal Rate of Return (IRR) (Green and Perry, 2008). While IRR allows comparing quantitatively investment options, its very formulation assumes a different hypothesis for investment and PH length. It relies on the inclusion of the initial investment in the equation for NPV calculation. This variation of NPV calculation is not designed specifically for repeated investment. For this purpose, the following equation is applied:

$$NPV_{TSL} = \sum_{i=1}^{TSL} \frac{Savings - Maintenance}{(1+IRR)^i} - RI \quad (3)$$

Where NPV_{TSL} ($) is the NPV for a single investment cycle (TSL = 15 y), RI is the Retrofit Investment ($). For estimating IRR, in Eq(3) is set NPV_{TSL}=0 and it is solved for IRR. The obtained IRR values are – Option 1: 0.4373; Option 2: 0.4320. It can be seen that, by IRR, Option 1 is about 0.5 % more profitable than Option 2, which makes both options almost equally attractive for investors at the stage of preliminary evaluation. Factoring in further parameters may allow making a firmer decision – e.g. borrowing a larger sum of money, combined with market risks may tend to push the decision in favour of Option 1.

4. Conclusions

This contribution has presented a conceptual analysis and a case study on asset management for evaluating HEN retrofit options. It has been found that the correct approach to evaluating retrofit projects is investment planning, based on the NPV estimation. The NPV values and the derivative intensive indicators as IRR depend very much on the chosen PH value and retrofit implementation mode.

Several important research questions can be also identified, for constructing a complete method for retrofit investment planning. The issues are related to the link between TSL and the depreciation period, maintenance related to service life and equipment reliability, unification of the modelling framework.

If allowed by regulations, the depreciation can be performed faster than the TSL. This would relax one of the assumptions made for the current paper and presents a key modelling issue – how to differentiate the accounting concept (e.g. depreciation period) from the reliability-related concepts (e.g. TSL or RSL).
The latter also leads to the question of reliability. How is the reliability expressed and related to the necessary maintenance and investments? When can a certain action be considered as only maintenance and when as an investment? One possible treatment can be that maintenance merely keeps the equipment performance within certain required limits, without affecting the RSL or reliability, while any extension of RSL and improvement of reliability would be considered as retrofits to be invested in.
From the provided conceptual analysis and the case study, it has become apparent that a uniform model framework is necessary, which allows enumerating and evaluating the possible technical and financial action sequences and choosing the optimal combination of those. One option is to base the further considerations on the work by Novak-Pintaric and Kravanja (2007) by extending their model for including a broader set of retrofit options. A further improvement can be the derivation of suitable simplified objective functions and/or ensuring the model convergence for more complex problems.

Acknowledgements

This research has been supported by the EU project “Sustainable Process Integration Laboratory – SPIL”, project No. CZ.02.1.01/0.0/0.0/15_003/0000456 funded by EU “CZ Operational Programme Research and Development, Education”, Priority 1: Strengthening capacity for quality research, in a collaboration agreement with the University of Maribor – Slovenia.

References

Asante N.D.K., Zhu X.X., 1997. An automated and interactive approach for heat exchanger network retrofit. Chem. Eng. Res. Des., 75, 349-360.

Bonhivers J.C., Srinivasan B., Stuart P.R., 2017. New analysis method to reduce the industrial energy requirements by heat-exchanger network retrofit: Part 1 – Concepts. Applied Thermal Engineering, 119, 659-669.

Brown S., 2018. Loan or Investment Formulas. <brownmath.com/bsci/loan.htm>, accessed 31/03/2018.

Flores J., Montagna J.M., Vecchietti A., 2015. Investment planning in energy considering economic and environmental objectives. Computers and Chemical Engineering, 72, 222–232.

Green D.W., Perry R.H., 2008. Perry’s chemical engineer’s handbook. McGraw-Hill, New York, USA.

Isafiade A.J., Short M., Bogataj M., Kravanja Z., 2017. Integrating renewables into multi-period heat exchanger network synthesis considering economics and environmental impact. Computers and Chemical Engineering, 99, 51–65.

Jackson J.R., Grossmann I.E., 2002. High-level optimization model for the retrofit planning of process networks. Ind. Eng. Chem. Res., 41, 3762-3770.

Menezes B.C., Kelly J.D., Grossmann I.E., Vazacopoulos A., 2015. Generalized capital investment planning of oil-refineries using MILP and sequence-dependent setups. Computers and Chemical Engineering, 80, 140–154.

Morrison A.S., Atkins M.J., Walmsley M.R.W., 2012. Ensuring cost-effective heat exchanger network design for non-continuous processes, Chemical Engineering Transactions, 29, 295-300.

Nemet A., Klemeš J.J., Varbanov P.S., Mantelli V., 2015. Heat Integration retrofit analysis-an oil refinery case study by retrofit tracing grid diagram. Frontiers of Chemical Science and Engineering, 9(2), 163-182.

Novak-Pintaric Z., Kravanja Z., 2007. Multiperiod investment models for the gradual reconstruction of chemical processes. Chem. Eng. Technol., 30(12), 1622–1632.

Pan M., Bulatov I., Smith R., Kim J.K., 2012. Novel MILP-based iterative method for the retrofit of heat exchanger networks with intensified heat transfer. Computers & Chemical Engineering, 42, 263-276.

Smith R., 2016. Chemical process: design and integration. John Wiley & Sons Ltd., Chichester, United Kingdom, ISBN: 978-1-119-09441-8, 30.

Soršak A., Kravanja Z., 2004. MINLP retrofit of heat exchanger networks comprising different exchanger types. Computers & Chemical Engineering, 28(1-2), 235-251.

Tjoe T.N., Linnhoff B., 1986. Using pinch technology for process retrofit. Chem. Eng. (New York), 93(8), 47-60.

Walmsley M.R.W., Lal N.S., Walmsley T.G., Atkins M.J., 2017, A modified energy transfer diagram for heat exchanger network retrofit bridge analysis, Chemical Engineering Transactions, 61, 907-912.

Yong J.Y., Varbanov P.S., Klemeš J.J., 2015. Heat exchanger network retrofit supported by extended grid diagram and heat path development. Applied Thermal Engineering, 89, 1033-1045.