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Process Heat Transfer Enhancement to Upgrade Performance, Throughput and Reduced Energy Use

Martin J. Gough

CALGAVIN Ltd, Station Road, Alcester, Warwickshire, B496PG, UK
martin.gough@calgavin.com

This paper summarises the views and experience of a company specialising in providing technical solutions for increasing the performance of heat exchangers used in the process industries. It comments on the technical opportunities available to a processor to reduce overall energy use. Emphasis is made to the use of enhancement technology retrofitted to existing heat exchangers. The content provides some understanding of the driving forces or otherwise for companies to invest in saving energy. Examples are provided setting out the benefits achieved using process enhancement technologies. It concludes with the view that the most economic investment in improved efficiency is to address the operation of existing exchangers first improving their performance before considering the costly and usually difficult option of buying and maintaining more plant.

1. Introduction

By the very nature of world market competition, process plants remain under continuous and often intensive pressure to improve throughput and reduce production costs. In reality the drive to constantly improve begins the moment a new plant comes on-line. Some flexibility is usually built into new plant designs, expecting modifications to be made at some time in the future. One should remember that all calculations used in the design of plants are approximations or have varying degrees of tolerance resulting inevitably in some changes or modifications being required almost immediately after start up. Even when a new plant is constructed to be similar to an existing operating plant the material produced can have sufficiently different properties to make it ‘off-spec’. Given the plant can be made to meet the original production criteria, increasing throughput usually brings economy of scale and improved return on investment. Overall it is predominantly financial pressures (profit) that drives the constant need for engineers to upgrade existing equipment or perhaps modify the process or, for a major upgrade, propose a complete re-vamp of the plant.

2. Proposed vision

Of course some key equipment, often large and expensive like furnaces, reactors, columns, principal pipe sizes, even power supply may not be easily or economically modified or upgraded and therefore remain the basic throughput limitation. Such equipment, single or multiple define the ultimate throughput available from the plant. Having said this there is nearly always a changing demand from refineries in terms of product output such as deeper cracking of crude to meet the requirement of higher value feed-stock to petrochemical plants. Another example is the pressure coming from legislation to produce low sulphur diesel requiring enormous investment in new plant and often modification to the existing one.

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All such changes put increased demand on the performance of heat exchangers. Based on well proven technical grounds this paper seeks to lobby greater acceptance of technologies that can be shown to provide substantially improved performance and reduced fouling in tubular heat exchangers. For the tube-side hiTRAN Enhancement Systems, tube inserts, provide a cost effective improvement option and for the shell-side specialist baffle arrangements such as helical baffles (CB&I – Lummus) and EMbaffles (grid type – Shell). Using combinations of these as appropriate provides performance flexibility that can be designed to meet a specific need. Figure 1, 2, and 3.

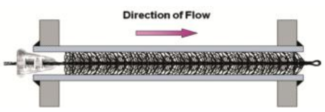

Figure 1: hiTRAN Matrix Element (CALGAVIN Ltd)

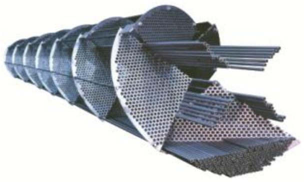

Figure 2: Helical baffles (Courtesy of CB&I – Lummus)

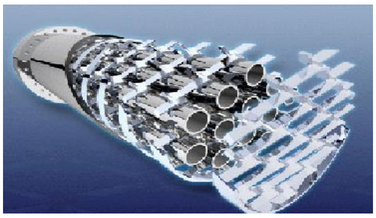

Figure 3: EMbaffle heat exchanger (Courtesy of EMbaffle B.V.)

Proposals to modify plants always come with some degree of risk, real or perceived. Most often the entire production of a plant will be affected and at risk from even a small modification. It is therefore an essential part of risk assessment that the information on which decisions are made are as close to reality as plant measurements can provide. The performance specification of original equipment may well be considerably different from its current duty making real measurements from the operating plant absolutely essential for predicting the expected and usually guaranteed new outcome. This is very much the case with heat exchangers. Even with new designs it is commonly held that using data for water will only provide an exchanger to be within +/- 10 %! For two-phase flow the accuracy is much lower and adding 'nominal' fouling margins the eventual size can result in a performance that maybe quite different from that expected. Having said this and with ever increasing computing sophistication, modelling can provide insight into not only design performance but also the expected variance that may inevitably occur. Sophisticated engineering software aimed at predicting plant performance under changed conditions such as control system modification, a new catalysts, different feedstock, new product type etc., have become essential 'tools' for the plant engineers striving to keep the plant competitive.

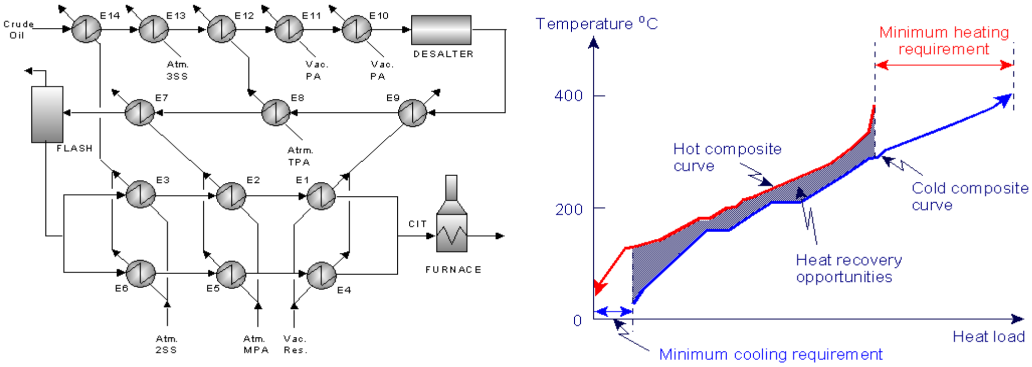

Figure 4: Heat recovery system optimisation – optimise HEN's to minimise energy costs. (Courtesy of Process Integration Ltd)

In the field of heating and cooling one such analytical methodology, developed by Professor Bodo Linnhoff and the UMIST team some 30 years ago (Linnhoff et al, 1982), has gained worldwide use in that with the ability to evaluate where temperature pinch occurs in a process, an operator can consider strategies to meet its energy target through heat recovery (Smith, 2005). Integrating a plant by the use of ‘Pinch Technology’ will benefit the design analysis process in terms of overall potential minimisation of energy for a given production level (Klemeš et al, 2010). Whilst providing the user with a very useful systematic methodology for assessing overall energy use across a plant, its implemented benefits have mostly been found in the design of new plants where exchanger sizing and positioning has some flexibility. For existing plants evaluating overall energy use and identifying areas for potential energy savings often results in the generation of side streams with more exchangers and pipework being added. Combining enhancement technologies with a systematic optimisation tool is an alternate and proven strategy to improve the operation of existing equipment. Through the cooperation initiative of Process Integration Ltd (PIL) and CALGAVIN Ltd this combination of technology and experience now provides practical solutions for the process industry (Pan et al, 2011). Figures 4, 5 and 6 illustrate the process optimisation opportunities for improving performance of exchanger networks and utilities.

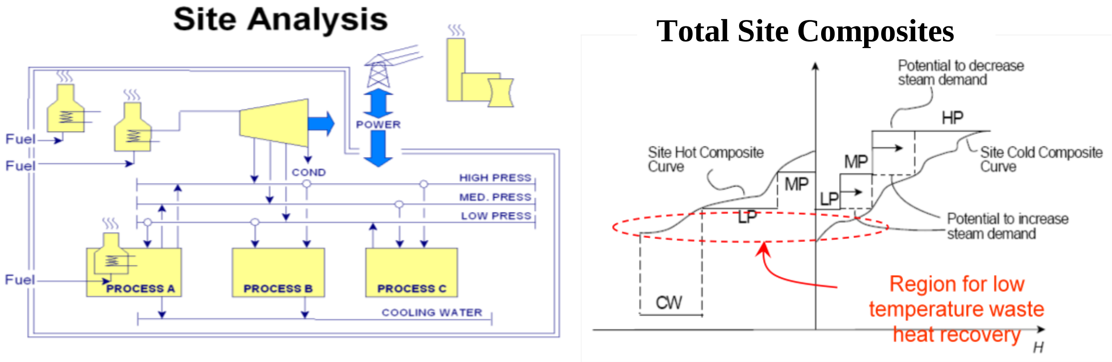

Figure 5: Utility system optimisation - to minimise energy costs, often at little or no cost (Klemes et al., 1997)

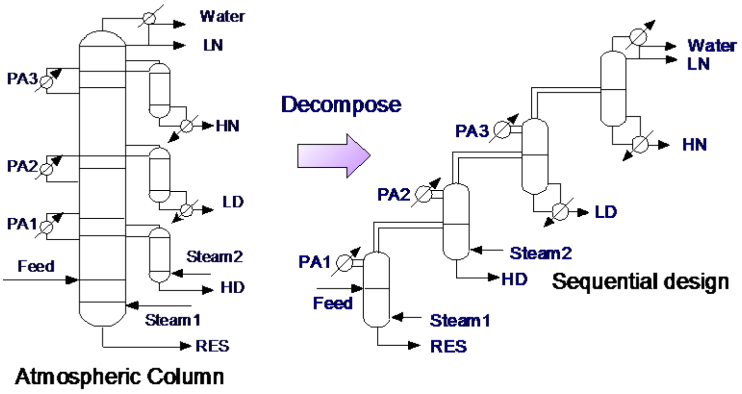

Figure 6: Crude Unit Refinery Optimisation - optimise pump around rates, steam rates, take-off flows, recycle loops, reboiler duties (Courtesy of Process Integration Ltd)

Adding more exchangers to an existing plant brings increased complexity but perhaps the most difficult practical issue is finding an appropriate place to position the units as often there is little or no space available within the compact structure of a process plant. Another issue that limits addition of new exchangers is the reluctance of processors to risk making any interventional changes to an operating plant delivering profit. Recovering energy simply for the sake of its value is rarely sufficient to risk production rate even if the calculations are deemed precise enough to provide the necessary predictions. Figure 7 shows the layout of a catalytic reactor process where the feed effluent exchanger was retrofitted to increase performance to achieve increased production. The viability of all schemes to reduce energy will be strongly influenced by the cost of the particular fuel, varying by location and of course influenced by the economic model, general taxation, carbon tax, and incentives etc., determined from the commercial/political stance of each country.

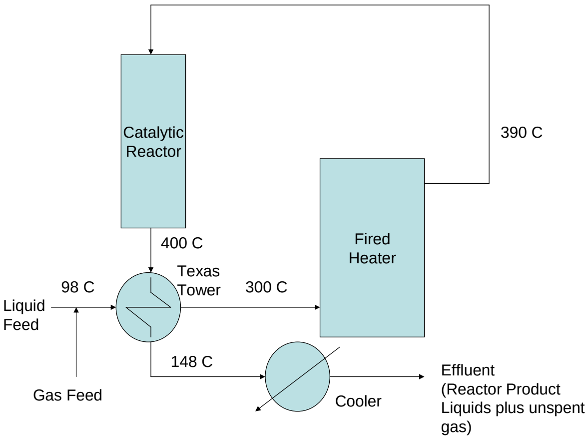

Figure 7: Heat recovery around reactor. The design of feed/effluent exchangers affects operating costs and significant savings can be made by effective retrofit for both energy saving and throughput improvement

Figure 8: Texas Tower (Courtesy of Ruhr Oel, Gelsenkirchen, Germany)

This commonly found low value of energy local to a plant is often so low that there would be insufficient return on capital for any serious investment in plant modification. One such potential integration project resulted in the cost of the exchangers, their transport and installation in a remote cold part of the world, being found never to result in an overall saving in the life of the plant. Whilst thermal integration has proven benefits for new green field sites, few pinch studies of existing plants, particularly refineries, have to date resulted in useful outcomes that have been implemented to provide process benefit. From the above it is evident that the risk and costs of adding new heat exchangers are greater than the benefits of reducing energy on most existing plants. The protocol set out by the Kyoto agreement will therefore have very limited impact unless ‘energy economics’ are changed.

It is interesting to note that the Japanese government have now taken a central role in its serious drive to reduce energy. Legislation and specific targets have been set for overall energy reduction on a national basis. A key force that added immediate focused to such large investment was the loss of electrical power from nuclear generation following the tragic effects of the recent tsunami. Effort has been galvanised across every industry and power user initiating a raft of cutting edge research projects hitherto only conceived as long term possibilities. Such is the investment by Japan that non domiciled companies like ours have been included under the New Energy and Industrial Technology scheme (NEDO) to provide specialist technical solutions.

Another very recent change has become evident in the Middle East. Until recently the value of energy used to heat and power refineries was valued internally at just $2 per barrel, in fact cheaper than the cost of local water! From this one can see that there is absolutely no incentive for plant operators to reduce or recover energy. We understand now that the Gulf Cooperation Council (GCC) countries have recently agreed a commercial protocol by which the accounting value has now increased to 20 US$/bbl, an incentive created to ensure effort by all refineries in the region to take responsibility and invest in energy efficiency. Other industries are impacted much more by the volatility of energy prices. Processors downstream of the ‘cheap’ refinery energy will view energy cost more carefully, energy efficiency having always been an issue. A 10 % improvement in energy efficiency is easily available on most plants by just implementing better control has been stated by a large chemical company in Germany, with another 10 -15 % saving if cost effective equipment improvements are made.

Global warming brings many challenges to the process industry. Increased daily temperatures reduces the efficiency of air cooled exchangers to a point whereby in some very hot countries such as Saudi Arabia increased ambient temperature can necessitate reducing production in the middle of the day to relieve increased column pressure through lack of condensing capacity. Such circumstances provide commercial stimulus to develop improved equipment design; optimised airflow, fluid distribution, drive systems, cleaning arrangements, fan designs etc. Table 1 below demonstrates very clearly the benefits of increasing tube-side heat transfer performance without incurring higher pressure loss. This is achieved by reducing the passes and effective flow length such that the pressure drop can be equal to that of the plain tube design.

Table 1: New air cooler design comparison with and without enhancement

Design Comparison	Empty tube design	Designed with hiTRAN
No. of bays/bundles	5/10	1/2
No of passes	12	2
Flow length, m	108	18
Tube-side HTC, W/(m^2 °C)	44	307
Overall HTC (bare), W/(m^2 °C)	35	180
Total Surface Area, m^2	18,100	3,600
Plot space, m^2	123.3	24.1
Weight, t	84	16
Total Fan Power, kW	165	33
Pressure Loss, bar	0.71	0.71
Annual cost of electrical fan power, US$	105,000	21,000

Key benefits include; reduced equipment size, smaller plot space, less maintenance, 80 % reduction in operating cost and at least 75 % reduction in installed cost.

Experience suggests the main incentive for investment in energy reduction comes from recovering heat and recycling it to provide a greater throughput thus the cost is paid for from the ensuing profit. By example a large feed heat exchanger on a Russian refinery was operating well below required performance exacerbated by mal-distributed flow through the 6 shells. The furnace capacity was at its limit precluding any opportunity of expanding throughput. A study, including the use of Computational Fluid Dynamics (CFD), to quantify the variation of individual bundle flow rates was commissioned. This led to the understanding that the tube-side coefficient could be increased to different levels within each bundle using proportional levels of enhancement. This technology, hiTRAN System, is well established now, changing tube-side flow regimes to turbulent and reducing fluid residence time at the tube wall to reduce fouling. The result was to recover 2.2 MW at the current low flow rate and facilitate increased throughput of the refinery. With increased production, heat recovery increased to 4.6 MW. Payback on energy alone was estimated to be about 12 months. Profit from increased throughput would reduce that to just a few months. This example was a simple relatively low risk project with very high returns and no plant modifications. Figures 9 and 10.

Addressing the need for more practical and economic retrofit solutions to reduce energy use on process plants has in recent years been the focus of considerable research funding and commercial development. One particular initiative being reported at this conference is 'Int-Heat Consortia' funded by the EU Framework 7 (INTHEAT, 2012). This is focusing on technologies that can enhance the operation of heat exchangers through energy recovery targeted at least 20 % savings. The consortia benefits from the variety and co-ordination of ideas and technologies provided by universities and Small Medium Enterprise's (SME) across Europe. Some technologies are in common use but need more data and exposure, others are in the development stage such as software to model exchanger networks with varied enhancements. Each has their particular application, limitation and associated design method.

Through collaboration the 'int-heat' project is bringing these technologies together providing different options for a variety of services. The work is beginning to resolve many of the technical obstacles hitherto found from having only an individual technology approach. Being developed is software that will be able to simulate the effects of retrofitting multiple types of exchangers with enhancement technologies within a process flow sheet. These include different types of enhanced tubes, tube inserts, improved types of baffle, higher performance fins and other products and techniques. It can be shown that with specialist software simulating a network of exchangers and correctly selecting the optimum combination of enhancement technologies, both improved throughput and reduced energy is readily achievable.

Figure 9: 6 shell exchanger; 30,000 tubes, partial condensation on the tubeside. (Courtesy of Lukoil, Russia)

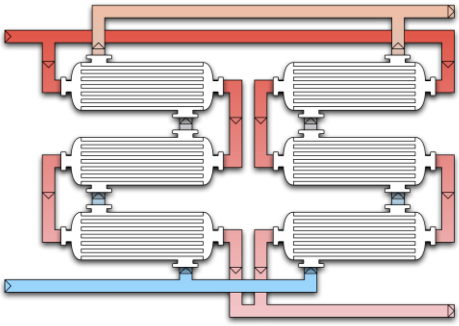

Figure 10: Bundle flow layout showing potential for misdistribution stemming from lack of stream control, (Courtesy of CALGAVIN Ltd)

3. Conclusion

If energy is to be saved on a large scale and on a global basis then processors taking ownership and responsibility for new plants should question the energy efficiency of the equipment and layout from the proposing contractor. Historically designers and builders of process plants have not been asked or paid to critically review better energy efficiency options, preferring to offer a no risk, easy to guarantee, repeat design. For existing plants, reducing energy can be more challenging, none the less the benefits available now from combinations of enhancement technologies can provide a real and practical contribution to greater energy efficiency. However, without the collaborative research and considerable support from universities in the UK and abroad, CALGAVIN would not be in the established position it is today providing the technical solutions needed to support its field of process energy optimisation.

Acknowledgement

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References

Klemeš J., Dhole, V.R., Raissi, K., Perry, S.J., Puigjaner, L., 1997. Targeting and Design Methodology for Reduction of Fuel, Power and CO_2 on Total Sites. Applied Thermal Engineering, 7, 993–1003

Klemeš J.,, Friedler F, Bulatov I, Varbanov P., 2010. Sustainability in the Process Industry. Integration and Optimization, McGraw Hill Companies Inc, USA, ISBN 978-0-07-160554-0, 362 ps.

Linnhoff, B., Townsend, D.W., Boland, D., Hewitt, G.F., Thomas, B.E.A., Guy, A.R., Marsland, R.H., 1982. A User Guide on Process Integration for the Efficient Use of Energy. IChemE Rugby, UK

Pan M, Bulatov I, Smith R, Kim J-K, 2011, Novel optimization method for retrofitting heat exchanger networks with intensified heat transfer, Proceedings of 21st European Symposium on Computer Aided Chemical Engineering, 29 – ESCAPE 21, 1865-1868.

Smtih R., 2005, Chemical Process Design and Integration. John Wiley and Sons Ltd, Chichester, UK.

Intensified Heat Transfer Technologies for Enhanced Heat Recovery – INTHEAT, <www.intheat.eu>, Accessed 15 July 2012.