Institution: **The University of Manchester**

Unit of Assessment: UoA12a Chemical Engineering

Title of case study: CPI – Centre for Process Integration

1. Summary of the impact

The field of conceptual chemical process design as practiced industrially has been influenced significantly by the outputs from the Centre for Process Integration (CPI) at Manchester. Process Integration Ltd (PIL) was spun-out from Manchester and currently employs over 50 staff globally, who have conducted projects that have resulted in annual cost savings of hundreds of millions of US dollars. The application of CPI technology has led to significant reductions in both energy costs and emissions of greenhouse gases. Since 2008 ca. US$350m of savings have been realized through the exploitation of CPI technology with US$1.4m generated from software sales.

2. Underpinning research

The impact is based on research that took place in Manchester between 1993-date by key researchers:-

- Robin Smith (Professor, 1984-date)
- X X (Frank) Zhu, (Senior Lecturer/Reader, 1993-2006)
- Gavin Towler (Lecturer, 1994-2002)
- Megan Jobson (Lecturer/Senior Lecturer, 1996-date)
- Nan Zhang (PhD Student/Lecturer, 1996-date)
- Simon Perry (Senior Teaching Fellow, 1986-date)
- Nii Asante (PhD Student/PDRA, 1993-1998)

Joao Alves (PhD Student, 1996-1999), MiMi Saine Aye (PhD Student, 2000-2003), Lu Chen (PhD Student, 2005-2009), Petar Varbanov, (PhD Student, 2001-2004), Yogesh Makwana, (PhD Student, 1994-1997), Fang Liu (PhD Student, 1998-2002).

Four areas of CPI's research activities that have generated significant impact will be discussed:-

1. Heat recovery systems

New approaches to heat exchanger design and retrofit were researched and developed that combine mathematical modelling with thermodynamic analysis. The approach has been proven to be particularly well-suited to the retrofit of existing heat recovery systems by allowing more cost effective improvement of existing processes. A fundamental understanding of the principles that underpin the limitations of existing heat exchanger networks has provided a much more systematic and practical insight [1]. In addition, the approaches developed for the design and retrofit of heat recovery systems have been able to be combined effectively with process models to allow much better improvements in profitability than when the heat recovery system is tackled alone [4].

2. Utility systems

Underpinning research conducted at Manchester has developed new and much more effective methods for the design and optimisation of complex utility systems. Such utility systems are a common feature of all chemical processing and are huge energy consumers. This has required an approach to modelling such systems that accounts for the part-load performance of equipment and at the same time allows more effective optimisation of the total system. The modelling environment developed has been implemented for system design and retrofit or for the operational improvement of an existing system with no capital expenditure [2].

3. Refinery hydrogen networks

Research at Manchester has developed systematic methods for improving refinery hydrogen networks – a critical feature of the design and operation of petroleum refineries. Various processes produce fresh hydrogen, produce waste hydrogen and consume hydrogen at different conditions.

Effective integration of these processes is critical to profitable operation. The methods developed provided for the first time insights into the complex interactions that take place. Graphical methods [3] have been developed, together with mathematical optimisation methods [5]. The methods set the minimum hydrogen supply required by the hydrogen network and allow systematic screening of purification processes for integration within the network. Prior to this work, no methods were available for the systematic analysis of refinery hydrogen networks.

4. Petroleum refinery molecular modelling

Petroleum refineries have conventionally modelled refinery streams and processes using only bulk properties, such as density, boiling point, etc. The composition of the streams has traditionally been considered to be too complex to allow a more fundamental approach. Research at Manchester has developed a way of modelling refinery streams and processes on a molecular basis. Critical to this is the ability to relate bulk properties to molecular make-up [6]. The molecular modelling approach can be used for the first time to manage the flow of specific molecular species through the refinery to allow better exploitation of the crude oil resource and increase profitability.

3. References to the research

The research was published in leading chemical engineering journals, including *Chemical Engineering Research and Design*, *Chemical Engineering Science* and *Industrial & Engineering Chemistry Research*. The research has had a considerable influence on the development of the field, as evidenced by the large number of citations (Google Scholar).

Key Publications

1. X X Zhu, N D K Asante "Diagnosis and Optimization Approach for Heat Exchanger Network Retrofit", AIChE Journal, 45(7): 1488-1503 (1999). (34 citations) DOI: 10.1002/aic.690450712
2. P Varbanov, S Perry, Y Makwana, XX. Zhu and R Smith, "Top-Level Analysis of Site Utility Systems", Chemical Engineering Research and Design, 82(A6): 784-795 (2004). (28 citations) DOI: 10.1205/026387604774196064
3. Joao J Alves, Gavin P Towler, "Analysis of Refinery Hydrogen Distribution Systems", Industry Eng. Chem. Res., 41: 5759-5769 (2002). (168 citations) DOI: 10.1021/ie010558v

Other Relevant publications

4. Smith R, Jobson M, Chen L, Recent Developments in the Retrofit of Heat Exchanger Networks, Applied Thermal Engineering, 30(16): 2281-2289 (2010). (20 citations) DOI: 10.1016/j.applthermaleng.2010.06.006
5. Liu F and Zhang N, "Strategy of Purifier Selection And Integration In Hydrogen Networks", Chemical Engineering Research and Design, 82(A10): 1315-1330 (2004). (74 citations) DOI: 10.1205/cerd.82.10.1315.46739
6. Mi Mi Saine Aye, N Zhang "A novel methodology in transforming bulk properties of refining streams into molecular information" Chemical Engineering Science, 60(23): 6702-6717 (2005). (20 citations) http://dx.doi.org/10.1016/j.ces.2005.05.033

4. Details of the impact

Context

The considerable supply of energy required by industrial production has focused attention on the more sustainable use of energy. Also, it is imperative that process efficiencies are improved to meet stringent regulations and environmental legalisation. Process Integration Technology (Pinch Technology) pioneered at Manchester was developed to address such issues and has been extensively used by the process industry worldwide.

Pathways to Impact

Manchester's CPI is a recognised centre of excellence and has maintained close links with industry through the Process Integration Research Consortium (PIRC). The computer software developed in CPI has enabled effective technology transfer and commercial exploitation of our underpinning research outputs by the thirteen companies comprising PIRC. In total, six software packages have been developed for heat recovery systems, utility systems, distillation systems cryogenic systems, water integration and refinery modelling & optimisation. Process Integration Ltd (PIL) was spun-out from Manchester in 2007 to provide an effective route to market. The software has been further developed to commercial standards and licensed by PIL, which currently employs over 50 people in Manchester, Beijing and Houston, for either sale to industry (14 copies, US$100k per copy) or for internal use by PIL on consultancy projects (35 major projects) [C1].

Reach and Significance of Impact

Heat Recovery Systems

Despite the cost saving and environmental benefits associated with reduced consumption of finite non-renewable energy resources, it is difficult to justify capital investment on retrofit for energy saving of an existing process.

The new methods developed in CPI have allowed more cost-effective retrofit of heat recovery systems and simultaneous heat recovery and process optimisation. To date, three software licences have been sold and sixteen commercial studies have been carried out on various process units from refining to petrochemicals. Savings related directly to the use of these CPI methods can be considerable [C2, C3], for example Sinopec has, since 2009, saved 15 MW of energy worth approximately US$25m, and savings will continue at a rate of ca. US$5m/year [C4]. BP envisages savings worth approximately US$4.4m/year per typical major refinery [C3].

Utility systems

Most processes operate in the context of an existing site in which a number of processes are linked to the same steam and power system. Such utility systems are the largest energy consumers on most processing sites and therefore offer the opportunity of substantial savings.

Manchester has developed improved methods for the simulation and operational optimisation of utility systems that have enable without capital expenditure substantial reductions in fuel consumption, fuel costs, increased power production and lower CO_2 emissions. Eleven commercial studies have been undertaken on utility systems for Sinopec resulting in energy savings of US$250m since 2009 and these savings will continue at a rate of ca. US$50m/year [C4]. In addition, revenue has been generated by licencing eight copies of the software to PCITC and LPEC in China.

Refinery hydrogen networks

After the cost of purchasing crude oil and the cost of energy to run a refinery, the next biggest cost is that of hydrogen. Changes in environmental regulations and increased use of heavy crude oil have increased the demand for hydrogen in refineries significantly. This has necessitated more efficient use of hydrogen and significant investment in hydrogen generation and purification, which consumes a significant amount of energy.

Manchester's systematic methods have for the first time provided petroleum companies with insight into how to improve the refinery hydrogen networks. Industrial process engineers have the benefit of not only powerful mathematical tools, but also the insights that simple graphical methods present.

Three software licences have been sold to Sinopec and PetroChina in China. Also, eight commercial studies have been undertaken on refinery hydrogen networks for Sinopec that have saved the company US$50M, since 2009, comprising savings in natural gas and additional revenue generated from the recovery of light hydrocarbons. These savings will continue at a rate of ca. US$10m/year. [C4]. In addition, a major study has also been carried out for Shell Deutschland, but the results are commercial in confidence.

Petroleum refinery molecular modelling

The demand for higher quality products in conjunction with more stringent environmental regulations has caused the refining industry to move towards better characterisation of the composition of refinery streams.

The methodology developed at Manchester allows more effective molecular management in refining through better modelling and optimisation.

Three commercial studies have been carried out on refinery optimisation for Sinopec that have saved US$25m, since 2009, in increased product value and on-going savings of ca. US$5m/year. More recently, PIL and Sinopec established a joint venture that has developed a new software system based on a research output from CPI. The software has the potential to make significant improvements in the efficiency of exploitation of crude oil. To date, the software has been validated on two Chinese refineries of Sinopec, two trial software licences have been issued for evaluation and is currently being launched commercially. The sales price of the software will be around US$225k per copy [C1].

5. Sources to corroborate the impact

C1. Letter from Process Integration Ltd – Software licensing and technology exploitation.

C2. Letter from ExxonMobil (USA) - Heat recovery Systems

C3. Letter from BP International - Heat recovery systems

C4. Letter from Sinopec - Heat recovery systems, Utility systems, Refinery hydrogen networks, and Petroleum refinery molecular modelling.