ENGINEERING PRACTICE

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SPECIAL FEATURE

Design of Waste Recovery Systems with Process Integration

IACPE
INTERNATIONAL ASSOCIATION OF CERTIFIED PRACTICING ENGINEERS
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ENGINEERING PRACTICE

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ABOUT

International Association of Certified Practicing Engineers provides a standard of professional competence and ethics. Identifies and recognizes those individuals that have meet the standard. And requires our members to participate in continuing education programs for personal and professional development.

In additional to insuring a professional level of competency and ethics the IACPE focuses on three major areas of development for our members: Personal, Professional, and Networking.

HISTORY

The International Association of Certified Practicing Engineers concept was formulated by the many young professionals and students we meet during our careers working in the field, running training courses, and lecturing at universities.

During question and answer sessions we found the single most common question was: What else can I do to further my career?

We found, depending on the persons avail able time and finances, and very often dependent on the country in which the person was from, the options to further ones career were not equal.

Many times we found the options available to our students in developing countries were too costly and or provided too little of value in an expanding global business environment.

The reality is that most of our founders come from countries that require rigorous academic standards at four year universities in order to achieve an engineering degree. Then, after obtaining this degree, they complete even stricter government and state examinations to obtain their professional licenses in order to join professional organizations. They have been afforded the opportunity to continue their personal and professional development with many affordable schools, programs, and professional organizations. The IACPE did not see those same opportunities for everyone in every country.

So we set out to design and build an association dedicated to supporting those engineers in developing in emerging economies.

The IACPE took input from industry leaders, academic professors, and students from Indonesia, Malaysia, and the Philippines. The goal was to build an organization that would validate a candidates engineering fundamentals, prove their individuals skills, and enhance their networking ability. We wanted to do this in a way that was cost effective, time conscience, and utilized the latest technologies.

MISSION

Based on engineering first principles and practical real world applications our curriculum has been vetted by academic and industry professionals. Through rigorous study and examination, candidates are able to prove their knowledge and experience. This body of certified professionals engineers will become a network of industry professionals leading continuous improvement and education with im-

VISION

To become a globally recognized association for certification of professional engineers.

LETTER FROM THE PRESIDENT

KARL KOLMETZ

WHAT ARE THE ODDS?

Dear Friends,

Welcome to November. I hope you are doing great. I reached the milestone of 60 years old October 5th. There are several things I have learned in the last 60 years.

1. The odds do apply to you.

When you are a young person looking at the odds of something happening you decide to take the risk because that will never happen to you. As you get older you decide not to take the risk because you have seen too many bad things happen to people who take risk.

2. At some point you will be in the right place at the wrong time.

If you decide to eat a cookie, and your dog knocks the cookie jar over and breaks the jar, it will look bad when your mother walks in sees the broken cookie jar and you with a cookie in your hand.

Of course as an adult the situation can be much worse than a broken cookie jar. Be prepared, at some point you may be in the right place at the wrong time.

3. We are blessed far more than we deserve.

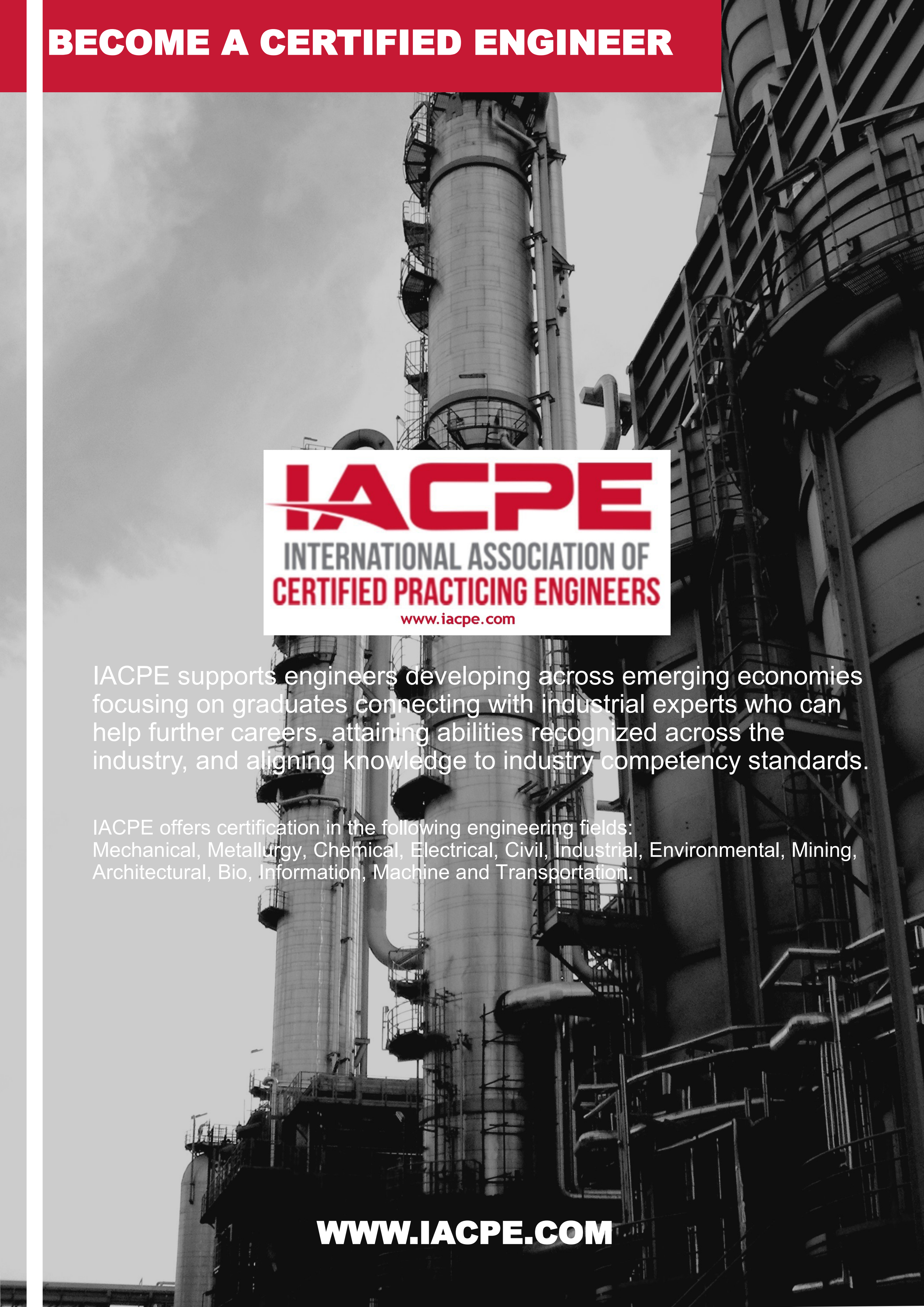
In my life I have many good friends who have treated me very well. I wish the demands of modern life were less, so I could spend more time with my friends.

I have been blessed with children and grandchildren. I spoke with an older lady in the Philippines and I asked her about her life. Her answer was: "I am not rich in many things, but I am very rich in children."

Most of us, if we truly did an internal reflection, would decide we are blessed far more than we deserve.

All the Best in Your Career and Life,

Karl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NEWS

IACPE PARTNERSHIP EXPANSION

We feel very honored that three universities have partnered with IACPE, and many more have expressed interest.

A University Partnership with IACPE would allow the students to gain knowledge, become certified and be a part of our international network of members.

We believe if you are looking for a university to attend, that you should strongly consider those universities that have partnered with IACPE to help build your practical knowledge during your studies, and certification for your professional practice.

We also are very honored that one engineering design company has chosen to train their engineering staff through IACPE. Give your employees the training they need for their engineering career and professional life with IACPE.

Partner Universities

We are honored that the following Universities had partnered with IACPE:

- August 2015
- Memorandum of Agreement (MOA) with Faculty of Engineering Universitas 17 Agustus 1945, Semarang, Central Java, Indonesia

Memorandum of Understanding (MOU) with Universitas 17 Agustus 1945 Surabaya and Memorandum of Agreenent (MOA) with Faculty of Engineering Universitas 17 Agustus 1945, Surabaya, East Jave, Indonesia

Memorandum of Understanding (MOU) with Universitas 17 Agustus 1945

Semarang, Central Java, Indonesia

Memoradum of Understanding (MOU) with Sekolah Tinggi Teknologi Fatahillah

Cilegon, Banten, Indonesia

INDUSTRY NEWS

Technip to supply hydrogen reformers at Petronas' RAPID project in Malaysia

Technip has been awarded by Tecnicas Reunidas a significant contract to supply three hydrogen reformers as part of the hydrogen production facility at Petronas' refinery andpetrochemical integrated development (RAPID) project located in the state of Johor, Malaysia.

As the heart of the hydrogen plant, the reformers will produce 344,500 Nm3/h of hydrogen and syngas products. It will supply high-quality export steam to the refinerysteam network. The supply of the reformers is based on Technip's proprietary top-fired steam methane reforming technology. The reformers are expected to come on-stream in 2018.

RAPID is Petronas' largest green-field downstream undertaking in Malaysia, and along with its six major associated facilities, forms the Pengerang Integrated Complex (PIC). The associated facilities are the Pengerang co-generation Plant, LNG re-gasification terminal, air separation unit, raw water supply project, the liquid bulk terminal and the central and shared utilities and facilities.

Puma to expand African fuel storage by near 40%

Puma Energy, whose largest shareholder is commodity trader Trafigura Beheer, will increase its fuel-storage capacity in sub-Saharan Africa by more than a third this year to meet rising demand.

The fuel supplier will add 350 million liters (92.5 million gal) of capacity to the 900 million liters it already has in the region, Christophe Zyde, chief operating officer for Puma Energy's African business, said in an interview. The expansion spans the continent from an aviation-fuel depot in Ghana to an oil-product terminal in Mozambique.

Demand growth in Africa is accelerating as transportation increases and energy use expands, attracting international investment in the fuel industry. Engen Petroleum, a unit of Malaysia's Petronas, said this month it would build a fuel terminal in Namibia, after opening a similar site in Mozambique a month earlier.

Puma Energy is still considering further projects and sees South Africa, the continent's most industrialized economy, as a target for investment, Zyde said. Burgan Cape Terminals is building a fuel-storage facility in Cape Town, which is due to be completed in early 2017.

"There is a need for imported product, there is a need for infrastructure, so that's where we start getting in," he said at Puma's offices in Johannesburg. The company's 110 million-liter mixed-product import terminal opening next month in Matola, Mozambique, is situated to supply its southern neighbor with cleaner fuels, he said.

Kuwait's KNPC awards EPC work to construct $16B Al-Zour refinery

Daewoo Engineering & Construction Co., Tecnicas Reunidas and Hyundai Heavy Industries Co. are among companies that signed contracts today to build Kuwait's $16-billion Al Zour oil refinery, which will more than double the nation's processing capacity.

The refinery, with a capacity of 615,000 bpd, will raise Kuwait total refining capacity to 1.4 million bpd when completed in July 2019, Mohammad Ghazi Al-Mutairi, CEO of state-owned Kuwait National Petroleum Co., said at the signing ceremony in Kuwait City.

The Al Zour refinery, valued at 4.87 billion dinars ($16 billion) will be integrated with a planned petrochemical complex which KNPC will discuss at an upcoming board meeting, he said.

"Al Zour refinery is one of the world's largest grass root plants being built from conceptual stage," Al-Mutairi said. "Al Zour refinery along with other ongoing mega projects will change the landscape of the oil refining industry in Kuwait. "

Phillips 66 unveils 2016 capital expenditures plan for refining, NGL projects

Phillips 66 plans $1.2 billion of capital expenditures in refining, with approximately 70% to be invested in reliability, safety and environmental projects, including compliance with the new Tier 3 gasoline specifications.

"The 2016 capital budget will fund Midstream growth and enhance returns in Refining," said chairman and CEO Greg Garland. "Cash from operating activities, our MLP and a strong balance sheet allow us to fund business growth while returning capital to shareholders."

DESIGN OF WASTE RECOVERY SYSTEMS WITH PROCESS INTEGRATION

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Synopsis

The rise of fresh resources costs, the increasingly stringent environment regulations and the awareness of sustainability developments are some of the reasons why efficient use of resources (such as water, utility gases and solvents) are gaining more attention in the chemical process industry. Fortunately, many industrial waste recovery problems share common features, which allow them to be handled using a common family of systematic techniques known as *process integration*.

In general, process integration techniques fall into two broad categories, i.e. *pinch analysis* and *mathematical optimisation* approaches. The former is often an insight-based driven, and hence is welcomed many process engineers. However, its limitation pertains to problem simplification. Mathematical optimisation on the other hand, serves the purpose for detailed planning/design, however is often suffers from providing good insights for process engineers. This article focuses on pinch analysis for the systematic design of waste recovery systems.

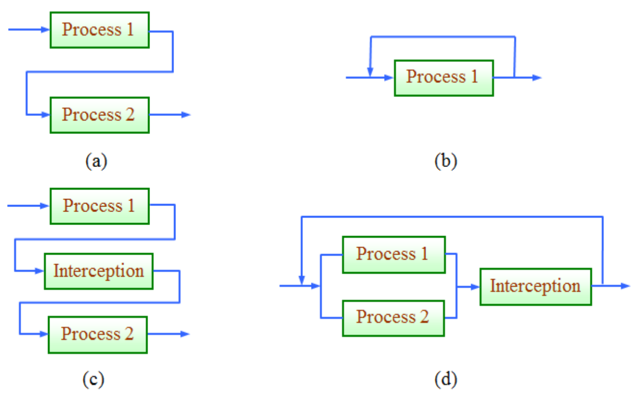
Background

Pinch analysis was originally developed as energy saving tools in the 1970s during the first oil crisis. To date, it is fully established and can be found easily in many chemical engineering design textbooks (e.g. Linnhoff et al., 1982; Smith, 2005). During the late 1980s, pinch analysis was extended into waste minimisation following analogy of heat and mass transfer (El-Halwagi, 1997). A special case later emerged in the mid-90s with the introduction of *water pinch analysis* (Wang and Smith, 1994), in which systematic design of a water recovery system was reported. By maximising in-plant water recovery, the fresh water intake and wastewater generation of the process are reduced simultaneously. In the following decade, two other similar variants were introduced, i.e. *hydrogen pinch analysis* (Alves and Towler, 2002) and *property pinch analysis* (Kazantzi and El-Halwagi, 2005). The former aims to reduce fresh hydrogen intake, which is an expensive utility for oil refineries and petrochemical plants; while property pinch analysis reduces fresh resources and waste material (e.g. solvent, solid feedstock) that are governed by physical property. In recent years, the design of waste recovery system for water, hydrogen and property are collectively termed as *resource conservation networks* – RCNs (Foo, 2012a). To design an RCN, pinch analysis makes use of the general principle of *quantity* and *quality* metrics for streams (Foo, 2012a). Quality metrics include impurity concentration in water and hydrogen pinch analysis, or property operator for property pinch analysis. On the other hand, quantity metric normally refers to material flow rate

Fundamental Theory

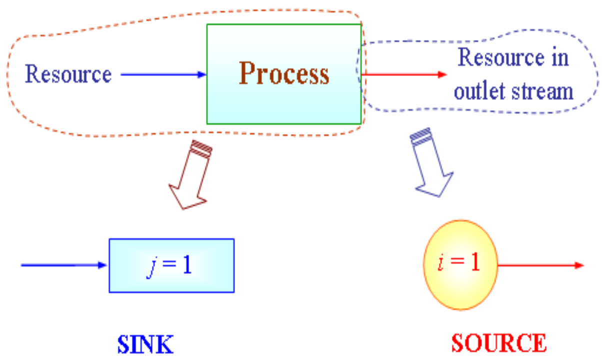
In the context of process integration, *material reuse* refers to the scheme where waste material from one process unit is channelled to another unit and does not re-enter the unit where it is generated (**Figure 1a**); while *recycle* allows the waste to re-enter the unit where it is generated (**Figure 1b**; Wang and Smith, 1994; Foo, 2012). When the maximum potential for direct reuse/recycle is exhausted, the waste material may be sent for *regeneration* in an *interception unit* (a purification unit that improves its quality, e.g. filter, pressure swing adsorption, etc.) in order for further reuse (**Figure 1c**) or recycle (**Figure 1d**).

Figure 1 Strategies for waste recovery: (a) direct reuse, (b) direct recycle, (c) regeneration-reuse, (d) regeneration-recycling



In order to design a RCN for waste recovery, the *material sinks* and *sources* are to be identified. Most often, the latter are outlet streams of processes that contain valuable resource. On the other hand, process sinks refer to units where the resource is consumed (see illustration in **Figure 2**). Hence, the recovery of sources to the sinks will help to reduce both fresh resource (and hence its purchase cost) and waste (and its treatment cost).

Figure 2 A material sink and source (Foo, 2012a)



To determine the minimum resource consumption and waste generation using the pinch analysis, one may make use of the graphical targeting tools such as the *material recovery pinch diagram* (El-Halwagi, 2006), or the algebraic approach of *material cascade analysis* (Foo, 2012a), which are now automated in a spreadsheet e.g. MS Excel (Ng et al., 2014).

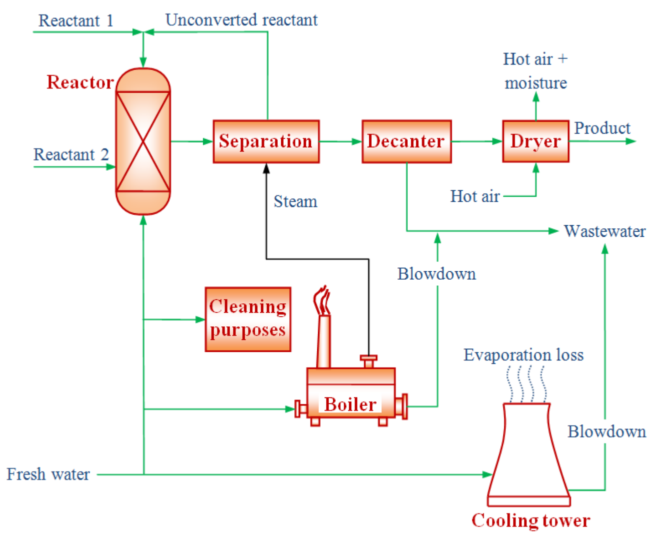
This is what we usually called as *benchmarking*, where best performance for waste recovery is determined using first principle, i.e. material balances.

In the following section, two examples are shown on how these pinch analysis tools can be used to design a waste recovery system.

Example 1: Water Recovery

Process flow diagram for a bulk chemical production is shown in Figure 3 (Foo, 2012b). Two gas phase reactants are fed to the reactor to be converted into the desired product with the present of water (as reaction carrier). In the separation unit, the unconverted reactant is recovered to the reactor, while the separated products are sent for downstream purification units, which consist of decanter and dryer. Wastewater is generated from the decanter due to the huge amount of water are used as reaction carrier, as well as the steam condensate in the separation unit. Besides, significant amount of water is also being utilised in the utility section of the plant. This includes the make-up water for boiler and cooling tower (with large evaporation lost), as well as water for general plant and vessel cleaning. Note that due to piping configuration, water for vessel cleaning also contributes to the decanter effluent. Apart from the decanter effluent, two other water sources are also found in the utility section, i.e. blowdown streams from the cooling tower and boiler.

Figure 3 Process flow diagram for a bulk chemical production (Foo, 2012)



It is desired to design a water recovery system for the process in order to minimise the flowrates of fresh water and wastewater. Limiting data to carry out water pinch analysis is summarised in Table 1. As shown, the limiting data contain of limiting flowrates for water sinks (F_{SKj}) and sources (F_{SRi}), as well as their impurity concentrations (C_{SKj} and C_{SRi} for sink and source, respectively). Suspended solid is taken as the primary impurity for water recovery, with fresh water being assumed to have zero impurity.

Figure 4 show that the material recovery pinch diagram for the bulk chemical production example. As shown, the minimum fresh water (F_{FW}) needed for the process have been reduced significantly to 11.1 kg/s, from its original value of 23.9 t/h (sum of all sink flowrates in Table 1). This corresponds to a reduction of 53.6%. On the other hand, the wastewater discharge (F_{WW}) of the process is reduced from 14.8 t/h (sum of all source flowrates in Table 1) to 2.0 t/h, corresponds to a reduction of 86.5%. A pinch is found at the concentration of source SR1, i.e. 20 ppm. This represents the most constrained area in the reuse/ recycle network where maximum recovery may be achieved. Figure 4 also shows that 12.8 t/h (F_{REC}) of water is being recovered between the sources and the sinks.

Table 1 Limiting water data for bulk chemical production example

j	**Sinks, SK*j***	**F_{SKj} (t/h)**	**C_{SKj} (ppm)**
1	Reactor	10.5	0
2	Boiler make-up	0.6	0
3	Cooling tower make-up	9.3	50
4	Cleaning	3.5	100
i	**Sources, SR*i***	**F_{SRi} (t/h)**	**C_{SRi} (ppm)**
1	Decanter	13.6	20
2	Cooling tower blowdown	1.0	400
3	Boiler blowdown	0.2	400

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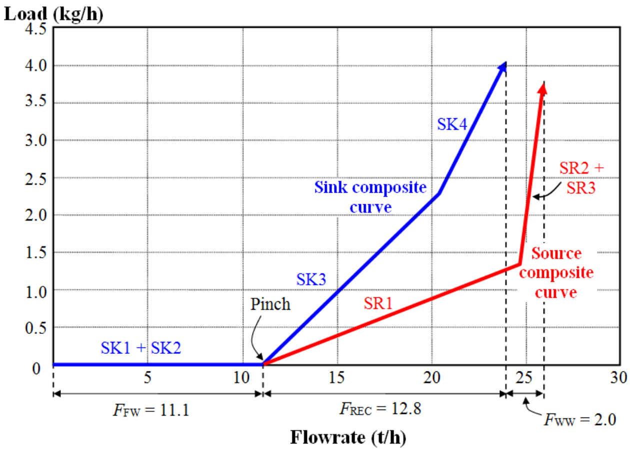


Figure 4 Material recovery pinch diagram for bulk chemical production example

To design a water recovery system for this simple case, one may easily observe from the pinch diagram (**Figure 4**) that fresh water is fed to sinks SK1 and SK2; while source SR1 is being reused to sinks SK3 and SK4. A portion of SR1 and the unutilised sources of SR2 and SR3 are discharged as wastewater. Hence, the water recovery system for the example is shown in **Figure 5**.

Example 2: Hydrogen Recovery

In recent years, the degrading of crude oil quality has forced many refineries to increase their capacity of hydro treating processes, in order to produce high quality chemicals to satisfy the increasingly stringent environmental regulations. This has led to increasing demand of hydrogen in the refineries, and also higher operating cost. Hydrogen pinch analysis has a major role to play, to reduce both hydrogen consumption and its cost.

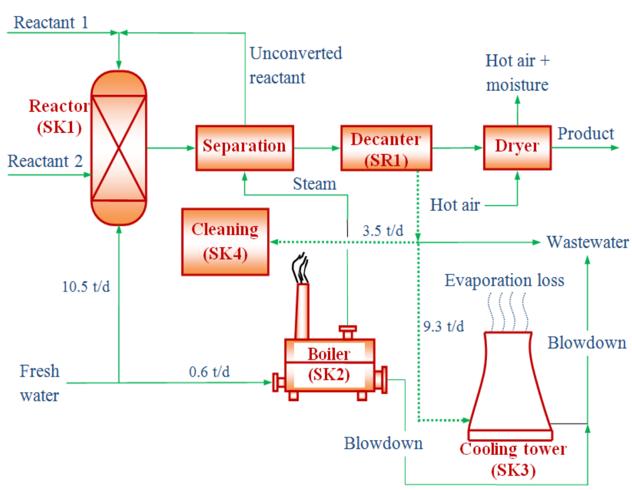


Figure 5 Water recovery system for bulk chemical production example (dashed lines indicate water recovery)

Figure 6 shows a process flow diagram for a simplified refinery hydrogen network (Hallale and Liu, 2001). At present, two hydrogen-consuming units A and B are fed by a fresh hydrogen source, and purge a significant amount of unused hydrogen as fuel. Note that both units have an existing internal hydrogen recycle stream. However, as will be shown, carrying out hydrogen pinch analysis enables more hydrogen to be recovered in the process.

Figure 6 A simplified refinery hydrogen network (flowrate given in MMscfd; impurity concentration given in percentage)

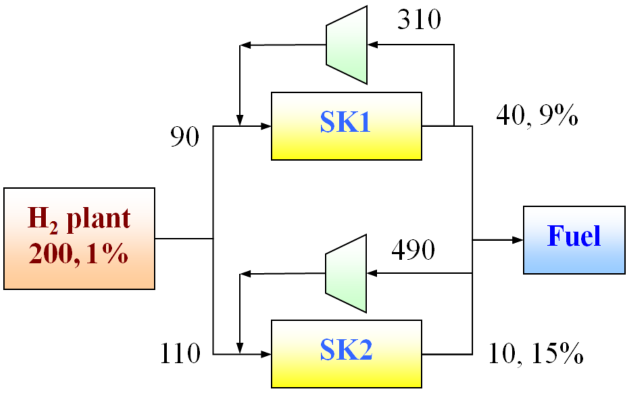
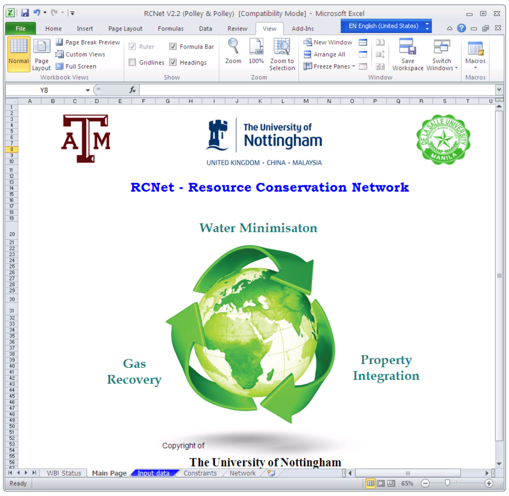


Table 2 Limiting data for simplified refinery hydrogen network

	Make-up stream	Recycle stream	Purge stream	Hydrogen sink, SK*j*	Hydrogen source, SR*i*
Unit A					
Flowrate (MMscfd)	90	310	40	400	350
Concentration (%)	1	9	9	7.20	9
Unit B					
Flowrate (MMscfd)	110	490	10	600	500
Concentration (%)	1	15	15	12.43	15

Limiting data for carrying out the hydrogen pinch analysis is given in **Table 2**. Note that the hydrogen source flowrate is the sum of the recycle and purge streams of the units; while the hydrogen sink flowrate is the sum of their make-up and recycle streams. Using a free pinch software of RCNet (Ng et al., 2014, see **Figure 7**), the minimum hydrogen utility needed for the refinery hydrogen network is determined as 183 MMscfd (F_{HU}), corresponds to a reduction of 8.5%. On the other hand, its waste gas that is sent for fuel burning is reduced by 34% to 33 MMscfd (F_{Fuel}). A hydrogen recovery system for this case is given in **Figure 8**.

(a)



(b)

Fresh source impurity	Fresh 1: 0 %	Fresh 2: 1 %	Fresh 3: 0 %
Fresh source flowrate	Fresh 1: 0 MMscfd	Fresh 2: 183.00 MMscfd	Fresh 3: 0.00 MMscfd
Discharge flowrate	33 mol/s		

Cascade Table

Row	C	ΔC	ΣF_j	ΣF_i local	ΣF_i fresh	$\Sigma F_i - \Sigma F_j$	F_C	Δm	Cum. Δm	$F_{FW,k}$	F_C	Δm	Cum. Δm
14											**0.00**		
15	0		0	0		0							
16		1					0	0			0.00	0.0	
17	1				**183.00**	183			0	0.00			**0.0**
18		6.2			(F_{HU})		183	1.1346			183.00	1.1	(PINCH)
19	7.2		400			-400			1.1346	157.58			1.1
20		1.8					-217	-0.3906			-217.00	-0.4	
21	9			350		350			0.744	82.67			0.7
22		3.43					133	0.45619			133.00	0.5	
23	12.43		600			-600			1.20019	96.56			1.2
24		2.57					-467	-1.20019			-467.00	-1.2	
25	15			500		500			0	0.00			**0.0**
26		999985					33	32999.51			**33.00**	32999.5	(PINCH)
27	1000000								32999.51	33.00	(F_{Fuel})		32999.5

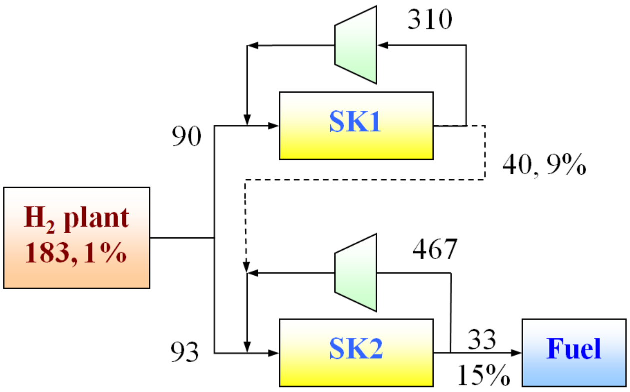


Figure 7 Targeting for minimum hydrogen utility and waste using RCNet

Figure 8 A hydrogen recovery system (dashed lines indicate hydrogen recovery; flowrate given in MMscfd; impurity concentration given in percentage)

Conclusions

This paper shows how waste recovery can be designed using process integration and pinch analysis techniques. By setting the minimum fresh resource and waste targets in prior, engineers can now identify the maximum possible saving that can be achieved in a waste recovery system. Apart from the water and hydrogen recovery examples, many other resource conservation cases (e.g. utility gas recovery, property integration) have also been reported in textbook (Foo, 2012).

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BIODATA

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