WATER PINCH ANALYSIS – A REVIEW OF RECENT JOURNAL PUBLICATIONS

VATTEN-PINCH ANALYS – EN ÖVERSYN AV DE SENASTE PUBLIKATIONERNA

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Abstract

As the population of the world increases, the demand for resources of different types will also grow. Water is one such resource. Pinch analysis, as a technique to optimise the utilisation of resources, had its origin in heat recovery and thereby the optimisation of fuel usage in the 1970s during the oil crisis. Since then, it has expanded to encompass a vast swathe of resources – both material and otherwise. Water pinch analysis is one offshoot of this tool (the implementation is labelled as pinch technology). This short article is a focused and selective review of recent publications having 'pinch analysis' in their titles and as their 'core and gist', during the period 2008–2018, and having water pinch analysis as either the sole focus or one of the foci.

Keywords: Optimisation, Pinch analysis, Water Pinch Analysis, Wastewater, Water cascade

Sammanfattning

I takt med att världens befolkning ökar kommer efterfrågan på resurser av olika slag också att öka samtidigt. Vatten är en sådan resurs. Pinch-analys, som en teknik för att optimera användningen av resurser, har sitt ursprung i värmeåtervinning och utvecklades för optimering av bränsleförbrukningen under 1970-talets oljekris. Sedan dess har den utvidgats till att omfatta en stor mängd resurser – både material och annat. Vatten pinch analys är en avknoppning av detta verktyg (genomförandet är märkt som pinchteknik). Denna korta artikel är en fokuserad och selektiv översyn av de senaste publikationerna med "pinch analysis" i sina titlar och som deras "kärna", under perioden 2008–2018, och med vatten pinch analys som antingen enda fokus eller en av de många.

Introduction

With the imminent rise in the population of the world, and the concomitant increase in the demand for water (in society and industry, the latter furnishing the former with the means of existence), optimisation of the use of water (sustainable consumption) alongwith supply-side measures like recycling of wastewater and the harnessing of water sources hitherto not utilised – desalination of sea water or brackish water for instance – will become more of a compulsion than a choice. When it comes to optimisation of the usage of water (improving the efficiency of water use and thereby truncating the water footprint of the products and services supplied to the global population, by seeking out opportunities for using water in a cascade within industrial process networks), pinch analysis as a technique which has its origin in heat recovery during the oil crisis, is a useful tool which has been and will be put to good use in the years to come (see Tan et al., 2015, which is also a review paper focusing on the prospects of pinch analysis in general, in the years to come).

The motive behind this short article is to perform a focused, selective review of recent publications having pinch analysis as their 'core and gist', and water pinch analysis as the sole focus or one of the foci. Pinch analysis performed to optimise the cooling load (and thereby the need for cooling water) is also under the purview of this review. Quite obviously, the articles reviewed form just a small subset of the several publications which form a strong foundation now, for research in this niche area of engineering and management.

Methodology

The author adopted a very simple approach to constructing a list of publications to be read and reviewed for this particular paper. The source referred to was Scopus. The restriction to Scopus was based on the fact that this is known to be the largest database which has access to most of the relevant publications on most scientific topics. Only 'pinch analysis' was used as the search-phrase, and the time-span was restricted to 2008–2018. The search-phrase was sought after only in article titles, under the assumption (which is quite reasonable) that any paper which focuses primarily on pinch analysis, as a methodology would surely include the term in the title. Just out of interest, the author wanted to browse through publications on pinch analysis in the said time-period, applied to all possible resources, before narrowing down the focus to water pinch analysis. While filtering out further, it was found that some articles related to orthopaedics and plasma physics were also listed- 'pinch analysis' being used in a more literal sense in those papers. These were excluded and the list whittled down to a little under 160 publications. A little less than 20 had their sole focus or one of the foci on the optimisation of the use of process water (as solvent or dilution agent), cooling water (related to the cooling load in thermal pinch analysis), or steam (as source of heat energy in processes). As shown in Table 1, the papers originate in different parts of the world – China, Iran, the Philippines, Mexico, India, UK, New Zealand and the Netherlands.

Table 1. *Sectoral and geographical classification of reviewed publications.*

Industry sub-sector	Sector	Publications	Country / Region
Oil and gas	Energy	Zhang et al. (2016)	China
		Bidhendi Nabi et al. (2010)	Iran
		Mohammednejad et al. (2011, 2012)	Iran
Biofuels	Energy	Tan et al. (2009)	The Philippines
Power production	Energy	Arriola-Medellin et al. (2014)	Mexico
		Patole et al. (2016)	India
		Patole et al. (2017)	India
Construction materials	Construction materials	Scouteris et al. (2010)	UK
Paper and pulp	Forestry	Li et al. (2018)	China
Water and wastewater	Urban systems	Esfahani et al. (2016)	Iran
		Li et al. (2010)	China
		Liang et al. (2017)	China
Chemical	Chemical, petrochemical and pharmaceutical	Jia et al. (2015)	China
	Chemical, petrochemical and pharmaceutical	Foo (2009)	China
Milk	Food	Walmsley et al. (2015)	New Zealand
		Walmsley et al. (2016)	New Zealand
Mushrooms	Food	Paudel et al. (2017)	Netherlands
Sugar	Food	Balla et al. (2018)	India

Discussion

Sectoral applications

The publications have been segmented based on the area/sector in which pinch analysis has been applied to study optimisation of the utilisation of water. Broadly, these are Energy, Chemical, pharmaceutical & petrochemical, Food, Urban systems, Construction materials and Forestry.

Energy

Power generation

Combined Pinch and Exergy Analysis or CPEA is an offshoot of pinch analysis which takes both thermal energy and mechanical energy (consumed by pumps, compressors, fans etc.), into consideration. This offshoot came in handy for Arriola-Medellin et al. (2014), who proved that elimination of cross-pinch heat transfer in a Mexican thermal power plant could increase the efficiency slightly by 0.81 percentage points, and bring down the cooling water requirement by 2.4%. If water scarcity is going to be a challenge to be faced in the future, courtesy climate change, any reduction in water demand is most welcome, anywhere in the world, in any sector.

Patole et al. (2016; 2017) have added to the body of knowledge related to multi-objective pinch analysis by developing what they term as a composite quality index, which factors in carbon footprint, water footprint, land footprint, 'emergy transformity', energy return on investment, human fatalities and inoperability risk, each of which is assigned a weightage using the well-known Analytic Hierarchy Process. In the same year as Patole et al. (2016) was published, Jia et al. (2016) applied multi-dimensional pinch analysis to the electricity sector in China, factoring in some of the aforesaid footprints/indices. Very recently, Lim et al. (2018) analysed the electricity sector in the United Arab Emirates using pinch analysis to examine the target the country's government has set for itself for the year-2050 – solar power dominating the power mix - and factoring in carbon footprint (to tackle global warming), water footprint (to consider water scarcity which is already an issue in the country) and the energy return on investment (economic sustainability).

Oil and gas

Zhang et al. (2016) have focused on both hydrogen and water as important resources for refineries and optimised the consumption of both of them, using pinch analysis. Water was the resource focussed upon in Bidhendi Nabi et al. (2010) and Mohammednejad et al. (2011; 2012), in a case study of the oil refinery in the Iranian capital Tehran. The freshwater use reduction achieved with double-contaminant and triple-contaminant water pinch analysis was 40% and 17.4% respectively. In Mohammednejad et al. (2012), the authors also considered each parameter – hardness, COD and suspended solids – separately, and arrived at 60%, 43% and 17% reduction in freshwater use respectively.

Biofuels – bioethanol and biodiesel

In a case study conducted in the Philippines, with sugarcane and corn considered as the possible sources of bioethanol production, Tan et al. (2009), studied the limitations imposed by freshwater resources in three selected regions in the archipelago for sugarcane/corn cultivation, on satisfying internal demand for bioethanol. While the focus was on water as a resource in this paper, the authors still recommended a multiple criteria pinch analysis, with land use and carbon emissions as the two additional criteria.

Chemical, pharmaceutical and petrochemical

In a review paper on water pinch analysis (or water network synthesis as it is alternately called), Foo (2009) have discussed the development in this particular application of pinch analysis in just the chemical sector over the years – starting from the 1990s, and well into the 21st century. Methane production from coal was the focus of Jia, X et al. (2015), but water was the resource under consideration, and water pinch analysis revealed that a reduction in freshwater use of 16% could be achieved with effective internal water cascading.

Food sector

Moving over from beer to milk, in two related publications – Walmsley et al. (2015) and Walmsley et al. (2016) - the authors have focused on the dairy sector in New Zealand, and suggested that appropriate placement of vapour recompression sub-systems (types of heat pumps) in a two-effect milk evaporation system results in the usage of 78% less steam vis-à-vis the status quo, though a little more electricity (16% more) will be needed in the process. Less steam implies a smaller water footprint for milk production. However, water scarcity is not a concern in New Zealand. Paudel et al. (2017), in a multi-objective pinch analysis (exergy pinch and water pinch) conducted within a mushroom canning facility in the Netherlands, have shown by rearranging the production process in order to facilitate easier energy recovery, the water footprint of the facility can also be truncated by 25% (when blanch water is fully reused). More importantly, if these changes are brought about, the yield of the facility can also be increased by 9%. Obviously, an economic analysis – a life-cycle costing more precisely – would be needed to find out if the investments in rearranging the process and installing heat exchangers, will be economically feasible, when the three benefit streams (yield increase, reduction in energy use, reduction in water use) are considered.

Balla et al. (2018), by conducting a water pinch analysis for a sugar factory showed that the freshwater extraction could actually – theoretically that is – be reduced to zero, if the vapour condensate which results when the water inherent in the sugarcane is separated from it and then cooled, can be completely recovered and used in the water-demanding sugar production processes within the factory. Sugar production is a water-intensive process, which of course can also benefit from the optimisation of the use of thermal energy as some other researchers have demonstrated.

Urban systems

Water and wastewater systems

Janghorban Esfahani et al. (2016) used water pinch analysis as a tool to determine that a solar-powered reverse osmosis (RO) desalination system which will be able to cater to the total demand for treated water in Kish Island (Iran), will entail the installation of 92 photovoltaic panels, 11 RO membranes and a desalinated water storage tank with a capacity of 63 m^3.

Pinch analysis in combination with mathematical programming enabled Li et al. (2010) to optimise wastewater treatment networks – the mixing, treatment and discharge of wastewater streams, and Liang et al. (2017) to show that freshwater use reduction is easily attainable in a plant with several water-consuming processes, each requiring water of a different quality (with respect to concentrations of specified pollutants).

Construction materials, paper and pulp

Take the process of coating in a paper and pulp mill for instance. Li et al. (2010) by zeroing in onto the drying section of the coating process unit in a paper and pulp mill, showed by using pinch analysis to explore energy recovery possibilities, that the energy saving potential could be more than doubled from the 4.82 MW that was extant at the time of conducting the analysis to almost 10 MW, reducing the need for fresh steam in the process, and thereby the demand for water.

Water Pinch analysis has been availed of by Scouteris et al. (2018) to optimise water consumption in a brick kiln in the UK. They compared two approaches – a direct water reuse/recycle using the water cascade approach – and water regeneration where effluent wastewater is treated in-situ and thus made reusable, and showed that in the case of the former, the water footprint could be reduced by about 16%, while in the latter, a truncation by over 56% could be achieved. In regions which combat water scarcity – and there will be several in the years to come, courtesy climate change – water pinch analysis could well be a 'life-saver tool'.

Conclusions and recommendations

Pinch analysis in general for resources of different types (the water-energy nexus bringing cooling water and steam into the picture), and water pinch analysis for the minimisation of freshwater consumption, in conjunction with the other sustainability analysis tools like Environmental Life Cycle Analysis, Social Life Cycle Analysis and Life Cycle Costing, will continue to be handy tools in the years to come, as the world grapples with a host of sustainability challenges in different parts of the world. In this paper, the time period was restricted to the previous decade 2008–2018. Considering that Foo (2009) was a review of water pinch analysis published in 2009, it is evident that there were more papers on this topic published before 2008, which have not been considered in this short review.

A short account of the strengths and opportunities of pinch analysis in general (and thereby water pinch analysis as well, in particular) will be apt in this concluding section of the paper. Pinch analysis, as many researchers have recommended, has the potential to significantly improve both the process design and the design process. Water pinch analysis is one of the many offshoots which have entrenched themselves over a short period of time. Water pinch analysis applied for site-wide integration will help more and more industrial units in the future to conceive a symbiotic network among themselves, which proves to be beneficial to all of them. Of course, absence of cooperation for mutual benefits, will be a hurdle to the implementation of pinch analysis recommendations. While water pinch analysis may be looked upon as a narrow approach missing the wood for the trees, multi-objective pinch analysis, which was also referred to in an earlier section, promises to be a cure.

The applications of pinch analysis (both thermal pinch which brings water into the picture; and water pinch analysis which deals with process water), as discussed in this article hail from different parts of the world , indicating the popularity and acceptance of this tool globally in research circles and a global recognition of the need to reduce the water footprint of society.

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