THE POTENTIAL FOR INDUSTRIAL WASTEWATER REUSE

C. Visvanathan
Environmental Engineering Program, Asian Institute of Technology, Pathumthani, Thailand

Takashi Asano
Department of Civil and Environmental Engineering, University of California at Davis, California, USA

Keywords: Agro-industries, Industrial reuses, Institutional aspects, Policy, Waste minimization

Contents

Summary

Continuous extraction of water has resulted in depletion of available water sources in and around the industrial areas. In addition, wastewater discharge into natural watercourses has caused surface and groundwater pollution, leaving water unsafe for potable use and impairing industrial use without major and costly treatment. The current low-cost end-of-pipe treatment approach will become increasingly expensive as effluent discharge standards become more stringent. Meanwhile, technological advancements now make it possible to treat wastewater for a variety of industrial reuses. Most industries in even developing countries are already moving towards wastewater reuse and source separation, and treatment of separated effluents is gaining more attention. The wastewater reuse potential in different industries depends on waste volume, concentration and characteristics, best available treatment technologies, operation and maintenance costs, availability of raw water, and effluent standards. Radical changes in industrial wastewater reuse have to take into consideration rapidly depleting resources, environmental degradation, public attitude and health risks to workers and consumers.

This article discusses the potential for industrial wastewater recycling and reuse and treatment technologies in attaining such a goal, in an increasingly competitive market and stringent regulatory environment.

1. Introduction

Since the Second World War, rapid development has improved the standard of living and quality of life for millions of peoples the world over. This growth has come at the cost of a thirty-fold increase in the use of fossil fuels and a fifty-fold increase in industrial production over the past century. As a result, significant amounts of once freely available natural resources have been consumed by industry, leaving the earth depleted for future generations. Much of the waste produced from these activities is directly discharged into natural water bodies. In developed countries, industry is the biggest consumer of water and accounts for 50% to 80% of total demand. This is far more than the 10% to 30% in developing countries where agriculture is the largest consumer. However, industrial water use is certain to increase over the next decade. In many countries, the high rates of consumption in the last decade have exceeded capacity to replenish dwindling water sources and put excessive pressure on existing resources driving up the cost of raw water for industrial applications.

Discharge of wastewater into natural water bodies is also increasing costs for industries located downstream and this translates into higher production costs which are inevitably passed on to consumers. This discharge is also exceeding natural purification capacities and depleting dissolved oxygen below levels which can support aquatic life. Meanwhile, industries using groundwater have caused severe damage to aquifers and their recharge capacity resulting in lower groundwater levels each year. For countries located in coastal areas, seawater intrusion is also threatening to make groundwater unsuitable for direct use.

Public awareness and government application of effluent standards has already forced many industries to implement appropriate treatment technologies. Initially, industries adopted simple physio-chemical treatment systems, but rapid degradation of the environment has forced governments to implement more stringent regulations for wastewater effluent and these standards have led to more advanced biological and membrane technologies.

As water for industrial applications becomes less easily accessible, industry is looking for ways to recycle and reuse treated water. Figure 1 shows how raw water for industrial applications can be supplied by recycling and reusing industrial and municipal wastewater.

Reusing wastewater is an attractive economic alternative and helps conserve an essential commodity for future generations. Economic use also reduces the quantity of waste diverted to treatment facilities and further lowers treatment costs. Companies invest in wastewater treatment and reuse not just to comply with effluent standards but because product recycling and raw material recovery benefit a company’s image as well as the bottom line. In contrast to agriculture, only a small fraction of industrial water is actually consumed. Most is discharged as wastewater.

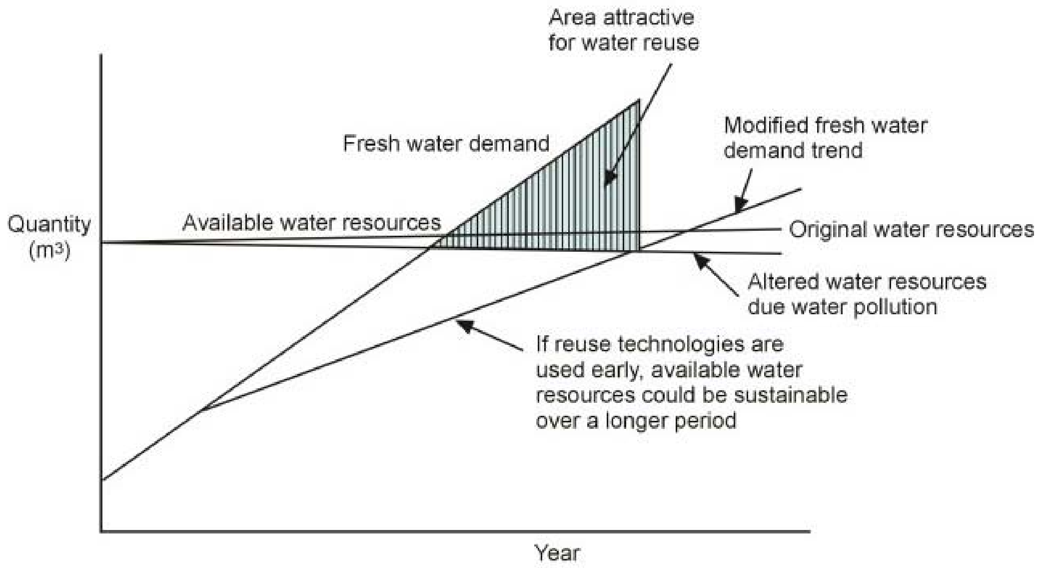

Figure 1. Wastewater recycling and reuse domain

Industrial wastewater treatment has taken place in a series of development phases (Figure 2) starting from direct discharge to recycling and reuse. This development has been slow considering the growing awareness of environmental degradation, public pressure, implementation of increasingly stringent standards, and industrial interest in waste recycling. The declining supply and higher cost of raw water is also forcing industry to implement recycling technologies. Many industries are now concentrating on methods to abate potable water intake and reduce discharge of polluted effluent. The move toward wastewater reuse is reflected in different "cleaner production" approaches such as internal wastewater recycling, reuse of treated industrial or municipal wastewater, and reuse of treated wastewater for other activities.

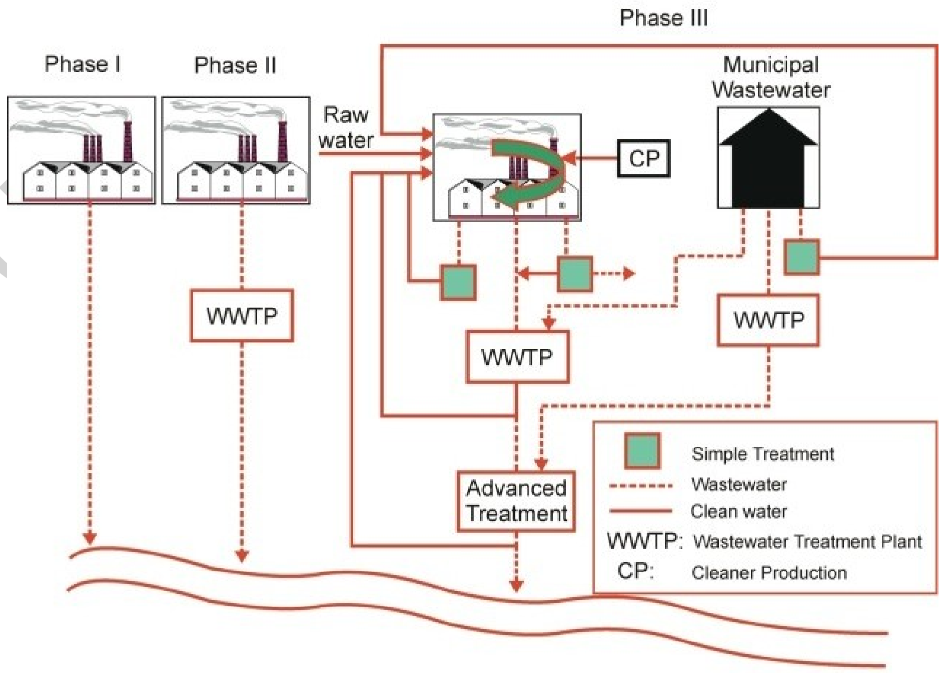

Figure 2. Development of industrial wastewater treatment and reuse

The potential for industrial wastewater reuse is dependent on a variety of factors and differs from one industry to another. Industries consuming a large volume of water obviously have greater potential for internal reuse. Similarly, simple physical and chemical treatments may be sufficient for wastewater produced from activities such as washing floors and cooling. Other industrial wastewaters have high concentrations of toxic chemicals, which must be removed, but this is actually an advantage if useable by-products can be recovered.

Programs for planned industrial recycling and reuse began in the USA in the 1940s when chlorinated domestic wastewater effluent was used for steel processing. In Sweden, a 5 to 6-fold increase in reuse was recorded from 1930 to 1970. During the last quarter of the century, the benefits of promoting wastewater reuse as a means of supplementing water resources have been recognized by most state legislatures in the United States and the European Union. Interest in reuse is now growing in other parts of the world in response to demand for high quality, dependable water supplies for agriculture, industry, and domestic uses but it has only been in the last quarter of this century that wastewater reuse technologies have been adopted in Asia. Practices implemented in China, for example, have resulted in an average rate of industrial wastewater reuse of 56% in 82 major cities in 1989, with a maximum reuse percentage of 93%.

2. Water Availability and Consumption

Of the estimated 44 538 km^3 of water available in the world, only 1% is fresh water; half of it in rivers, lakes and swamps. Readily accessible water for human use is about 0.007% of all the water on the planet. Although the total water available is sufficient to meet estimated demand at present, distribution is not uniform. Table 1 shows total water balance per continent. America, Australia and Oceania have the highest per capita water resources. Asia has far less. Asian countries must therefore think more seriously about conservation because the available per capita water is decreasing every year while consumption has been growing at more than twice the rate of population increase.

Continent	Annual stream		Water resources per inhabitant (Thousand m^3 per year)		
	Volume (km^3)	Total percentage (%)	1960	1980	2000
Africa	4570	10	16.5	9.4	5.1
Asia	14,410	32	7.9	5.1	3.3
Australia	348	1	28.4	19.8	15.0
Europe	3210	7	5.4	4.6	4.1
North and Central of America	8200	18	30.2	21.3	17.5
Oceania	2040	5	132.0	92.4	73.5
South of America	11,760	27	80.2	9.7	28.3
World	44,538	100	13.7	9.7	7.1

Source: Food and Agriculture Organization URL: http://www.fao.org/

Table 1. Water balance per continent

-
-
-

Bibliography

Andersen I., Lenes M., and Mosbye J. (1999). Closed water systems in Norwegian mills. *Water Quality International*, May/June, 38–38. [Provides extensive reports on closed water systems adopted in various industries in Norway.]

Anderson J. M. (1996). Current water recycling initiatives in Australia: scenarios for the 21st century. *Water Science and Technology*, **33**(10–11), 37–43. [Provides comprehensive information on recycling and reuse of stormwater and industrial wastewater in Australia.]

Asano, T. (1991). Planning and implementation of water reuse projects. *Water Science and Technology*, **24**(9), 1–10. [Describes waste reclamation and reuse using tertiary treatment processes and also includes cost economic analysis.]

Asano T., Mujeriego R., and Parker J. D. (1989). Evaluation of industrial cooling systems using reclaimed municipal wastewater. *Water Science and Technology*, **20**(10), 163–174. [Describes the results of study on cooling water using municipal wastewater, problems associated and economic analysis.]

Bickers P. O. and Bhamidimarri R. (1998). Aerobic treatment of reverse osmosis permeate in the dairy industry for reuse. *Water Science and Technology*, **38**(4–5), 61–67. [Technical report of pilot and batch scale experiments on wastewater from dairy industry using reverse osmosis in New Zealand.]

Blackson D. E. and Moreland J. L. (1998). Wastewater reclamation and reuse for cooling towers at the Palo Verde nuclear generating station. *Wastewater Reclamation and Reuse* (ed. T Asano), 1143–1162. Lancaster, PA: Technomic Publishing Co., Inc. [Report on case study of reclamation of municipal wastewater for cooling towers.]

Bonomo L., Nurizzo C., and Rolle E. (1998). Advanced wastewater treatment and reuse: related problems and perspectives in Italy. *Advanced Wastewater Treatment, Recycling and Reuse, Conference Proceedings*, 14–16 September 15-22. Milan, Italy. (ed. T Asano), [Gives an overview of water availability and distribution, water consumption and wastewater treatment trends in Italy.]

Carmichael J. B. and Strzepek K. M. (1987). Industrial water use and treatment practices. UNIDO. [Explains various types of industrial wastewater reuse processes and reuse trends in various industries around the world.]

Economopoulos A. P. (1993). *Assessment of Sources of Air, Water, and Land Pollution.* WHO Geneva. [This explains the methods of assessing various sources of air, water and land pollution.]

Farnrich A., Mavrov V., and Chmiel H. (1998). Water reuse in the food industry. *Advanced Wastewater Treatment, Recycling and Reuse, Conference Proceedings*, 14–16 September, (ed. T Asano), 1127–1130. Milan, Italy. [Explains the process of treatment of low concentrated wastewater from food industry using membrane technology and UV radiation.]

Guo G. L., Tseng D. H., and Yo S. H. (1998). Ozone treatment of sewage effluent as cooling water make-up. *Advanced Wastewater Treatment, Recycling and Reuse, Conference Proceedings*, 14–16 September, (ed. T Asano), 181–188. Milan, Italy. [Report on ozone treatment of sewage effluent to be used as cooling water and its effectiveness to control corrosion and scale formation.]

Hamoda M. F., and Al-Awadi S. M. (1996). Improvement of effluent quality for reuse in a dairy farm. *Water Science and Technology*, **33**(10–11), 79–85. [Research report on study of chemical treatment of wastewater from dairy firm in order to improve effluent quality and evaluate applicability of treated effluent in irrigation.]

Hansen P. (1989). Criteria for sustainable development management of transnational corporations. *Industry and Environment,* **12**(3–4), 32–35. [Describes various criteria for sustainable development of transnational corporations.]

Koyuncu I., Topacik D., Kinachi C., and Turan M. (1998). A study on recycling and reuse of acryclic fibre manufacturing industry effluents using membrane technology. *Advanced Wastewater Treatment, Recycling and Reuse, Conference Proceedings,* 14–16 September, (ed. T Asano), 1107–1110. Milan, Italy. [Describes the treatibility and reusability of acryclic fiber manufacturing industry effluents using reverse osmosis and nanofiltration.]

Kuylenstierna J. and Najlis P. (1998). The comprehensive assessment of the freshwater resources of the world-policy options for an integrated sustainable water future. *Water International,* **23**(1), 17–20. [This is a comprehensive report on global water availability, various water uses and future perspectives.]

Lopez A., Ricco G., Ciannarella R., Rozzi A., Di Pinto A. C., and Passino R. (1998). Textile wastewater reuse: ozonation of membrane concentrated secondary effluent. *Advanced Wastewater Treatment, Recycling and Reuse, Conference Proceedings,* 14–16 September, (ed. T Asano), 133–140. Milan, Italy. [Experimental study report on effectiveness of ozonation for the treatment of textile wastewater and toxic and/or inhibitory pollutants.]

Maeda M., Nakada K., Kawamoto K., and Ikeda M. (1996). Area-wide use of reclaimed water in Tokyo, Japan. *Water Science and Technology,* **33**(10–11), 51–57. [Comprehensive report on existing conditions of reclaimed wastewater use, quality criteria, and cost economic analysis in Shinjuku district in Tokyo.]

Odendall P. E., Westhuizen J. L. J., and Grobler G. J. (1998). Wastewater reuse in South Africa. *Wastewater Reclamation and Reuse* (ed. T Asano), 1143–1162, Lancaster, PA: Technomic Publishing Co., Inc. [Describes the different technological options available for wastewater reclamation and reuse in industries and existing laws and regulations related to reclamation and reuse in South Africa.]

Postel, S. (1997). *Last Oasis: Facing Water Scarcity.* The worldwatch environmental alert series. New York: WW Norton and Company. [Extensive report on global water availability, consumption and future perspectives.]

Rigoni-Stern S., Szpyrkowicz L., and Grandi F. Z. (1996). Treatment of silk and Lycra printing wastewater with the objective of water reuse. *Water Science and Technology,* **33**(8), 95–104. [Explains the treatment processes for the wastewater produced from printing matrix washing and by dyestuff leakage in silk and Lycra printing industry, to obtain acceptable effluent quality.]

RIZA (1999). Closing loops. *Water Quality International,* Jan/Feb. 38–40. [Explains two different closed loop options; concentration techniques and biological techniques, for paper industries.]

Roeleveld P. J., and Maaskant W. (1999). A feasibility study on ultrafiltration of industrial effluents. *Water Science and Technology,* **39**(5), 73-80. [Describes the application potential of ultrafiltration and reverse osmosis process for treatment of wastewater from food, chemical and paper industries.]

Rozzi A., Antonelli M., and Arcari M. (1998). Membrane treatment of secondary textile effluents for direct use. *Advanced Wastewater Treatment, Recycling and Reuse, Conference Proceedings,*14–16 September, (ed. T Asano), 797–804. Milan, Italy. [Experimental study report of pilot scale membrane modules for direct reuse of polished effluent within dying process.]

Rozzi A., Malpei F., Bonomo L., and Bianchi R. (1999). Textile wastewater reuse in Northern Italy (COMO). *Water Science and Technology,* **39**(5), 121–128. [Report on pilot scale experimental study on secondary effluent using activated carbon adsorption and membrane filtration.]

Suprihatin S., Schories G., Geiben S. U., and Vogelpohi A. (1998). A low energy membrane process for biomass separation: a new possibility for wastewater treatment and reuse. *Advanced Wastewater Treatment, Recycling and Reuse, Conference Proceedings,*14–16 September, (ed. T Asano), 479–484. Milan, Italy. [Experimental report on bench scale experiment on aerated crossflow submerged and non-submerged membranes for biomass separation.]

Tanik A., Sarikaya H. Z., Eroglu V., Orhon D., and Ozturk I. (1996). Potential for reuse of treated effluent in Istanbul. *Water Science and Technology,* **33**(10–11), 107–113. [Evaluates potential sources of effluent reuse and application based on technical, financial, economic, environmental and health consideration.]

UNEP/IE. (1996). Environmental management in pulp and paper industries. *United Nations Environment Programme, Industries and Environment. Technical Report No 4.* [A broad spectrum of environmental management in pulp and paper industries including waste minimization and recycling is explained in this report.]

Yalcin F., Koyuncu I., Ozturk I., and Topacik D. (1998). Pilot scale UF and RO studies on water reuse in the corrugated board industry. *Advanced Wastewater Treatment, Recycling and Reuse, Conference Proceedings*, 14–16 September, (ed. T Asano), 455-462. Milan, Italy. [Pilot scale experimental study report on treatment of colored effluent from paper industry using a two-stage membrane (ultrafiltration and reverse osmosis) system.]

Yi H. Kim., J. Hyung, H. Lee S., and Lee C. H. (1998). Wastewater recycling in the Kimchi Industry. *Advanced Wastewater Treatment, Recycling and Reuse, Conference Proceedings,*14–16 September, (ed. T Asano), 657–664. Milan, Italy. [Describes the result of an experimental study for treatment of wastewater from brining and rinsing using chemical precipitation and microfiltration.]

Zabel T. F., Anrews K., and Rees Y. (1998). The use of economic instruments for water management in selected EU member countries. *Journal of CIWEM*, **12**, 268–272.[Discusses the use of abstraction and effluent charges applied in France, Germany, England to assess the impact of application of economic instruments.]

Zhenhui (1989). Countermeasures for industrial water conservation in China. *Industry and Environment*, **13**,(3–4), 13–14.[Describes how China achieved a great progress in developing closed, multiple recycling system after enactment of laws in 1970s.]

Biographical Sketches

C. Visvanathan, is an Associate Professor of the Environmental Engineering Program, School of Environment, Resources and Development, Asian Institute of Technology. He has a Ph.D. (Chemical /Environmental Engineering) from Institute National Polytechnique, Toulouse, France. His main areas of research interests include: solid–liquid separation technologies for water and wastewater treatment, waste auditing and cleaner production and solid waste disposal and management. He has published more than 50 international journal and conference papers. Dr. Visvanathan's professional experiences include: Project Engineer, Asia Division, International Training Center for Water Resources Management, Sophia Antipolis, France, and short term consultant to UNEP Industry and Environment Office, Paris, France.

Takashi Asano has been engaged in both theoretical and practical research in wastewater reclamation, recycling and reuse for over 15 years. He has a Ph.D. in 1970 from Univ. of Mich, Ann Arbor. He was a U.S. representative for the International Association on Water Quality as the vice chairman, and is the honorary chairman of the Specialist Group on Wastewater Reclamation, Recycling and Reuse. He served as the chairman of the scientific and technical committees for the First International Symposium on Wastewater Reclamation and Reuse in Castell Platja d' Aro, Costa Brava, Spain in September, 1991, and the Second International Symposium on Wastewater Reclamation and Reuse in Iraklio, Greece in October, 1995. Professor Asano taught at the NATO Advanced Study Institute at Acquafredda di Maratea, Italy, and was the invited speaker at the Stockholm Water Symposium in Sweden. Professor Asano served as the Kubota Endowed Chair Visiting Professor of Environmental Engineering at the University of Tokyo and the Nishihara Endowed chair at Hokkaido University, Sapporo, Japan.