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INDUSTRIES AND WATER RECYCLING AND REUSE

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Abstract This paper presents importance of water recycling and reuse in industries in the context of efficient and sustainable water resources management. The three major uses of water within industry are for heat dissipation, power generation, and processing. Often 50 % or more of the water intake to plant may be used for the purpose of process cooling alone, a need that can often be met with lesser quality water saving the potable water for truly potable needs. The paper includes more specifically the discussions on benefits, scopes, methods, treatment alternatives, and common problems associated with water recycling and reuse. Meeting the needs of industry and using water efficiently to satisfy environmental and societal concerns need not be mutually exclusive. Brief, but a comprehensive industrial water management scheme is presented in this paper to illustrate management inputs required at the industry and the regional or governmental level.

Keywords Industries; water quality; water recycling; water reuse; wastewater treatment.

Introduction

The economic pressure of international competition, regulatory and social pressures for pollution control and water conservation have resulted in improved environmental performance in industry. In several developed countries, industry is the largest consumer of water, accounting for 50 to 80 % of the total water demand compared to about 10 to 30 % demand from the industries in the developing countries, where agriculture is the largest consumer (Postel, 1992). However, water use in the developing countries is rising at a significant rate due to rapid industrial development and bursting population. During the last decade, the rate of consumption in several countries has exceeded the capacity to replenish dwindling water sources putting excessive pressure on existing resources and proportionally increasing the cost of raw water for industrial applications.

While raw water is becoming expensive, problems are intensifying with the disposal of wastewater as well. Unwarranted discharge of wastewater into natural water bodies has led to two-fold problems: (1) increasing the cost of water treatment for industries located downstream, and (2) more importantly, exceeding natural purification capacity of the water bodies. In addition, industries using groundwater as their source of raw water supply have caused severe overdraft of groundwater aquifers, reducing their recharging capacity and resulting in lowering groundwater tables. In many coastal areas, groundwater overdraft has resulted in seawater intrusion deteriorating the quality of groundwater and making it unsuitable for beneficial use.

Thus, business and industry are increasingly being held accountable for the impact of their activities in the society. In response, they are striving to meet these challenges through improved practice. Technology is rapidly being developed which allows industrial operations to be designed and constructed with efficient water management as a prime objective. Many industries have included sophisticated treatment technologies (e.g. bioreactors, membrane technologies, advanced oxidation) beyond the traditional wastewater treatment process trains. This has also led industries to consider efficient use of water through water conservation, and water recycling and reuse. Water recycling and reuse is now widely believed to be one of the primary steps of efficient and sustainable water use, achieved by reducing the freshwater demand and the associated reduction in wastewater discharge (Asano, 1991).

Wastewater recycling and reuse and their benefits

To facilitate communication among different groups associated with water recycling and reuse, the following definitions are provided. *Wastewater reclamation* is the treatment or processing of wastewater to make it reusable, and *water reuse* is the use of treated wastewater for beneficial purposes such as agricultural irrigation and industrial cooling. *Reclaimed water* is a treated effluent suitable for an intended water reuse application. In addition, *direct* water reuse requires the existence of pipes or other conveyance facilities for delivering reclaimed water. *Indirect* reuse, through discharge of an effluent to receiving water for assimilation and withdrawals downstream, is recognized to be important but does not constitute *planned direct* water reuse. In contrast to direct water reuse, *water recycling* normally involves only one use or user and the effluent from the user is captured and redirected back into that use scheme. In this context, water recycling is predominantly practiced in industry, which is the subject of this paper.

Water recycling and reuse has far reaching benefits in industries beyond the mere requirement of complying with the effluent discharge permits, as follows:

1. Reduction in freshwater withdrawal and consumption
2. Minimization of wastewater discharge by reclaiming wastewater, thereby reducing cleanup costs and discharge liabilities
3. Recovery of valuable by-products
4. Improvement of the profit margin by cost reduction
5. Enhancement of corporate image, public acceptance, and environmental responsibility

Development of water recycling and reuse

Industrial wastewater treatment has gone through a series of developmental phases from preliminary treatment techniques to most advanced techniques allowing recycling and reuse, which generally requires high effluent quality. Figure 1 shows a conceptual framework for the development of water recycling and reuse. This development has been slow, compared to the rate at which the environmental damages progressed and the subsequent growth of environmental awareness in the communities. However, recent crises of dependable freshwater supply and higher cost of raw water have forced industries to rapidly adapt to the situation by implementing water conservation and recycling technologies. Many industries are now concentrating on methods to abate potable water intake and to promote zero discharge, which eliminates the need for an environmental permit but can be costly. The move towards water reuse is often associated with implementation of *cleaner production* techniques which may also include internal water recycling, reuse of treated industrial or municipal wastewater, use of treated wastewater for other activities.

Programs for a large scale planned industrial recycling and reuse began in the U.S.A. in the 1940s, when chlorinated municipal wastewater effluent was used for steel processing. In Sweden, a five to six fold increase in reuse was recorded from 1930-1970. During the last quarter of the century, the benefits of promoting water reuse as a means of supplementing water resources have been recognized by most state legislatures in the United States and in Europe. Interest in water recycling and reuse is now growing in other parts of the world in response to demand for high quality, sustainable water supplies for agriculture, industry, and domestic uses. It is only during this period that water reuse technologies have been adopted in industries in Asia. In China, for example, the average rate of industrial wastewater reuse was about 56% in 82 major cities in the year 1989, with a maximum reuse of 93% (Zhenhui, 1989).

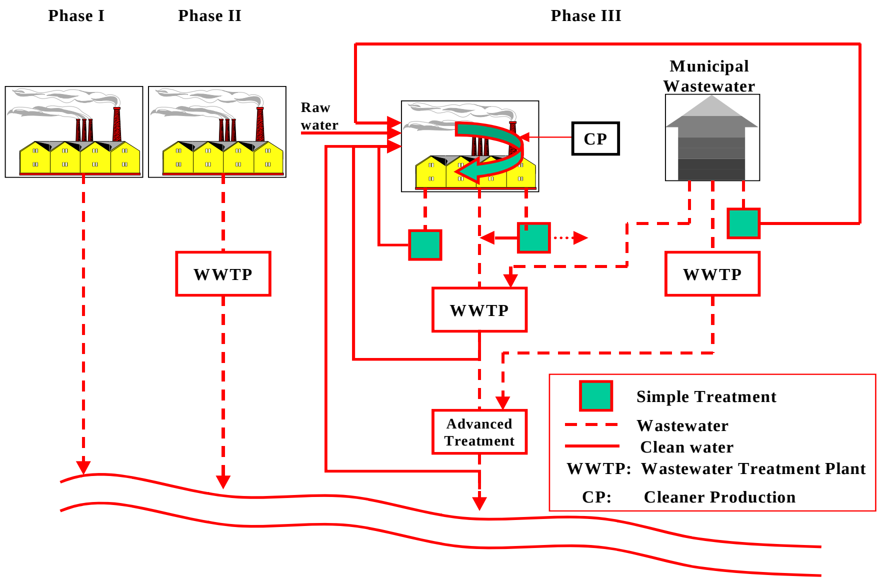

Figure 1. Development of the concept of water recycling and reuse

Scopes of water recycling and reuse in industries

The three major uses of water within industry are for heat dissipation, power generation, and processing. Often 50 % or more of the water intake to plant may be used for the purpose of process cooling alone, a need that can often be met with lesser quality water saving the potable water for truly potable needs. The potential for industrial wastewater reuse depends on a variety of factors that differs from one industry to another. However, the concept of water recycling and reuse works well for industries as only a small part of the supplied water ends up in the product while the major part is spent as wastewater. Figure 2 shows how demand and supply of raw water identifies conceptually the possible opportunities for water recycling and reuse.

Although globally water withdrawal is increasing, the rate is slowing down in the industrial sector of many western countries owing to more conservation, recycling and reuse. In the United States, for example, water intake is reduced from 280 m^3/t to 14 m^3/t of manufactured steel while in Germany, intake reduced from 700 litres/t to 7 litres/t of paper (Andersen *et al.*, 1999). Although industry uses much less water compared to agriculture, it is the cause for the heaviest source of pollution. In general, the following four types of industries are ideal candidates for water recycling and reuse:

1. Industries consuming high volumes of water for process activities (e.g., pulp and paper, power plants)
2. Industries discharging highly toxic effluent to natural bodies of water
3. Industries producing wastewater with potential for by-product recovery, mainly for economic benefits (e.g., photographic processing)
4. Industries with growing demands for water consumption

The potential use of reclaimed water for industrial processes depends on the water quality requirement. For example, the electroplating industry requires almost distilled water for washing circuit boards and electronic components whereas tanneries can use relatively low quality water for washing hides. The scope of water recycling and reuse varies according to the type of industry, the requirement of the process, the type of wastewater produced and the treatment technology used. Simple physico-chemical treatment may be sufficient for wastewater produced from some activities like floor washing, while wastewater containing such contaminants as heavy metals, toxic chemicals, refractory inorganics may need advanced treatment or may be considered for products recovery.

Segregation of waste (based on volume and concentration) is one of the most important factors in designing a water recycling and reuse program. For example, a less contaminated wastewater from a final rinsing operation could be collected separately, and recycled to the pre-washing unit. Whereas highly polluted wastewater could be sent to the effluent treatment units, where it is treated to meet the required effluent discharge standard. It is essential to determine the type and volume of waste to be recycled. Thus, the scope of recycling is governed by various internal factors as well as several external factors such as availability of raw water, possibilities of expanding the processing units, effluent discharge standards and recovery of byproducts from wastewater treatment (RIZA, 1999). Table 1 summarizes the potentials for water recycling and reuse in different industries.

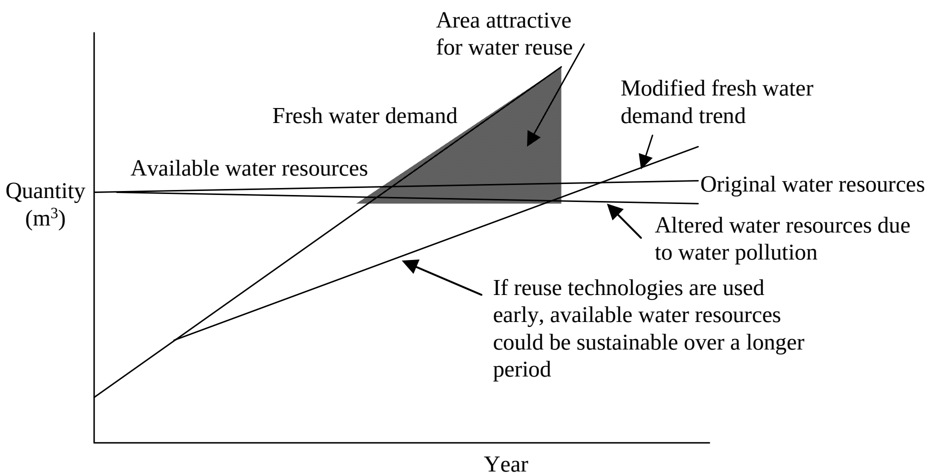

Figure 2. Water recycling and reuse domain

Table 1 Wastewater recycling and reuse potential for industries

High Potential	Medium Potential	Low Potential
Cooling towers	Slaughterhouse	Tanneries and leather finishing
Pulp and Paper	Dairy	Pesticide
Cotton Textile	Canning and Food Processing	Rubber
Pulp and Paper	Distillery	Aluminum
Glass and Steel	Wool Textile	Explosives manufacturing
	Photographic Processing	Paint manufacturing
	Chemical	
	Fertilizer	
	Oil refining	
	Petroleum	
	Electroplating	
	Meat Processing	

Adapted from Hansen, 1989; Byers, *et al*, 1995

Wastewater recycling and reuse schemes in industries

The two main schemes of water recycling and reuse are discussed:

1. Internal water recycling
2. Use of reclaimed municipal wastewater for recirculating cooling towers

Internal wastewater recycling In this scheme a part of the wastewater generated can be used back in the process after appropriate treatment depending upon the water quality requirement of the manufacturing process. It is estimated that by internal recycling water consumption can be reduced by 50 to 95%. Table 2 presents percent recovery possible in several industries in Japan. The average industrial water recovery in 1997 was 77.9 percent (Water Resources of Japan, 2000).

Table 2 Percent recovery of industrial water in Japan

Industry	(%)
Iron and Steel Industry	87.0
Chemical Industry	81.0
Food Manufacturing Industry	28.3
Textile Industry	16.7

Adopted from Japanese Land Agency (2000)

Use of reclaimed municipal wastewater for recirculating cooling towers For industries such as electric power generating stations, oil refineries, and many types of chemical and metal plants, one-quarter to more than one-half of a facility's water use may be cooling tower make-up. Because a cooling tower normally operates as a closed-loop system isolated from the process, it can be viewed as a separate water system with its own specific set of water quality requirements, which are largely independent of the particular industry (State of California, 1979).

Treated secondary effluent has been successfully used as cooling tower make-up water at the Palo Verde Nuclear Generating Station (PVNGS) in Arizona, U.S.A. It consists of three identical pressurized water reactors and turbine-generators. Each unit generates 1,270,000 kilowatts of electricity - a total of 3,810,000 kilowatts. The PVNGS is unique because it is the only nuclear energy facility in the world that uses treated sewage effluent as a source of water for cooling tower operation. Secondary effluent from the cities of Tolleson and Phoenix is pumped 61 km to this site. Before using the effluent, it is subjected to advanced treatment at the on-site Water Reclamation Facility consisting of (1) biological nitrification, (2) lime and soda ash addition for softening and phosphorus removal, (3) filtration, and (4) chlorination. The purpose of the advanced treatment is to reduce corrosion and scaling in the cooling tower systems. The WRF was designed to produce economical cooling tower make-up water in sufficient quantities and quality to support the operation of three nuclear power plants (Blackson and Moreland 1998).

Water and salt balance in cooling tower A concept of *cycles of concentration* associated with water and salt balance is important in water recycling in industries. Using the recirculating cooling system as an example, material balance for water and salt is developed below. Under normal operating conditions, the loss of water, discharged from the cooling tower to the atmosphere as hot moist vapor, amounts to approximately 1.2 percent for each 5.5°C of cooling range. Drift, or water lost from the top of the tower to the wind is the second mechanism by which water is lost from the cooling system. About 0.005 % of the recirculating water is lost in this way (Burger, 1979). While evaporation results in a loss of water from the system, the salt concentration is increased because salts are not removed by evaporation. To prevent the formation of precipitates in the resulting concentrated tower water, a portion of the concentrated cooling water is bled off and replaced with low salt make-up water to maintain a proper salt balance. This highly saline water bled off from the cooling tower system is called *blowdown*.

The total make-up water flow for the cooling tower system includes all three of the water losses described above (i.e., vapor loss, drift, and blowdown). Figure 3 shows a definition sketch of the recirculating cooling system. Referring to Figure 3 the water balance around a cooling tower can be described as:

In = out

$$Q_m = Q_b + Q_d + Q_e \tag{1}$$

where Q_m = make-up water flow, L/min

Q_b = blowdown flow, L/min

Q_d = drift flow, L/min

Q_e = evaporation loss, L/min

Drift flow, Q_d, is normally small enough to be ignored (< 0.005 %).

In a similar way, the salt balance in the cooling tower is

$$Q_m C_m = Q_b C_b + Q_d C_d + Q_e C_e \tag{2}$$

where C_m = salt concentration in make-up water flow, mg/L

C_b = salt concentration in blowdown flow, mg/L

C_d = salt concentration in drift flow, mg/L

C_e = salt concentration in evaporation loss, mg/L

Because Q_d is negligible, the term Q_dC_d can be omitted without serious error. Further, because the concentration of salt in the evaporation water is also negligible under normal operating conditions Eq. (2) can be reduced to Eq. (3).

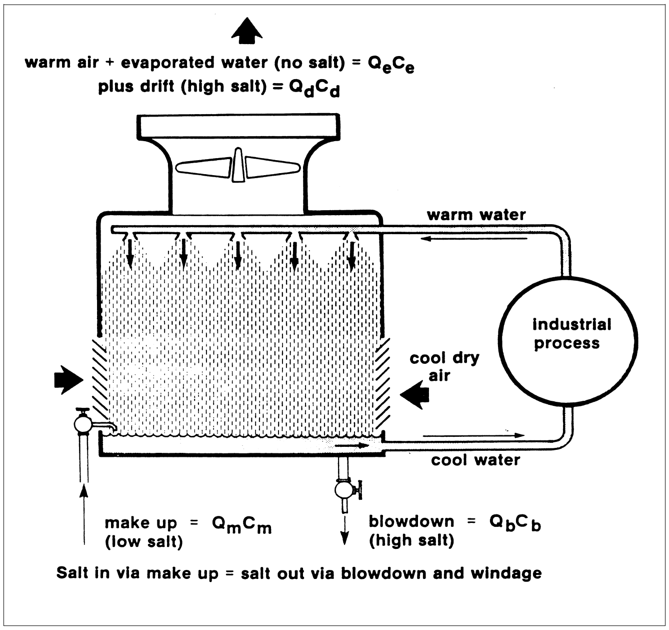

Figure 3 Definition sketch of the recirculating cooling system

$$Q_mC_m = Q_bC_b \qquad (3)$$

The magnitude of the blowdown flow (and thus, the make-up flow) is dependent upon the concentration of potential precipitants in the make-up water. The ratio of the concentration of the salt C_b in the blowdown to its concentration C_m in the make-up water is known as the *cycles of concentration*.

$$\text{Cycles of concentration} = C_b/C_m \qquad (4)$$

Combining Eqs. (3) and (4) yields

$$\text{Cycles of concentration} = Q_m/Q_b \qquad (5)$$

It can be seen in Eq (5) that the *cycles of concentration* also equal the ratio of the make-up flow to the blowdown flow.

When the *cycles of concentration* are on the order of 3 to 7, some of the dissolved solids in the circulating water can exceed their solubility limits and precipitate, causing scale formation in pipes and coolers. To avoid scale formation, sulfuric acid is often used to convert calcium and magnesium carbonates into more soluble sulfate compounds. The amount of acid used must be limited to maintain some residual alkalinity in the system. If the pH of the system is reduced to far below 7, accelerated corrosion can occur.

Increasing the cycles of concentration was investigated as a way to reduce the volume of discharge. It was found that side-stream filtration would allow cycles of concentration to be significantly increased from five to about 20 without fouling of condenser surfaces with silica. Increased cycles of concentrations to 20 would reduce the volume of blowdown by 80 % (Chatfield, 1982).

Applicable wastewater treatment technologies

The degree of treatment required varies according to the specific reuse application and associated water quality requirements. The simplest treatments involve solid/liquid separation such as sedimentation; the common treatment includes aerobic biological treatment, oxidation ponds, biological nutrient removal, and disinfection. More complex treatment involves combination of physical, chemical, and biological processes by employing multiple barrier treatment approaches for contaminant removal such as activated carbon, air striping, ion exchange, chemical coagulation and precipitation. More advanced technologies include microfiltration, nanofiltration, ultrafiltration, reverse osmosis, and advanced oxidation. Use of membrane technology has been successful in removing most contaminants from wastewater thereby increasing the potential for even greater recycling and reuse. The advantages of membrane technologies are small footprint requirement compared to other systems, better process control, and potential for intermittent operation. Successful removal of dye concentrations from 6-9 g/L to 0.01 mg/L in an acrylic fiber plant in Istanbul using a two stage RO process and bioreactors combined with aerated membranes can also be used in pulp and paper and textile wastewater treatment (Tannik *et al*, 1996). Membrane technology provides an attractive alternative to expand a range of water recycling and reuse applications. Table 3 presents typical wastewater treatment requirements as a function of end industrial water use application.

Table 3 Treatment technology for water recycling and reuse for industrial water supply

Industrial water use	N and P removal	Chemical precipitation	Filtration
Cooling tower makeup	Normally	Yes	Yes
Once through cooling			
- Turbine exhaust condensing	Sometimes	Seldom	Sometimes
- Direct contact cooling	Seldom	No	Sometimes
- Equipment and bearing cooling	Yes	Yes	Yes
Process water	Yes	Yes	Yes
Boiler feed water	Requires more extensive treatment; use of reclaimed wastewater generally not recommended		
Washdown water	Sometimes	Seldom	Yes
Site irrigation	No	No	Normally

Common water quality problems related to use of reclaimed water

Six general water quality problems are encountered in use of reclaimed water: (1) scaling, (2) corrosion, (3) biological growth, (4) fouling, (5) foaming, and (6) pathogenic organisms. Both freshwater and reclaimed water contains constituents that can cause these problems, but their concentrations in reclaimed water are generally higher.

Scaling Scaling refers to the formation of hard deposits, usually on surfaces, which reduces the efficiency of heat transfer process. This problem is not only associated with the use of reclaimed water but also for freshwater used as feed water in cooling towers. Due to repetitive recycling of feed water in the cooling water a significant water is lost (by evaporation) leading to increase in the concentration of impurities such as calcium, magnesium, sodium, chloride, and silica, which eventually lead to scale formation. Scale forming constituents can be eliminated using appropriate chemical precipitation techniques. Advance treatment techniques such as ion exchange or reverse osmosis can also be used to reduce scale forming calcium and magnesium salts but cost is much higher.

Corrosion Corrosion is accelerated by many contaminants present in the wastewater. Ammonia, which may be present in significant concentration in the reclaimed municipal wastewater, may be one of the prime causes of corrosion in many industrial water reuse installations. It is corrosive to copper alloys and also increase chlorine demand during disinfection. Stripping and nitrification can eliminate ammonia. Contaminants such as TDS increase the electrical conductivity of the solution and thereby accelerate the corrosion reaction. Dissolved oxygen and certain metals (manganese, iron, and aluminum) promote corrosion because of their relatively high oxidation potential The corrosion can be controlled by adding chemical corrosion inhibitors (especially in case of excess total dissolved solids).

Biological growth Slime and algal growth are common problems in reclaimed water due to high nutrient content, which promotes biological growth. Biological slime settles and binds other debris present in the cooling water, thus inhibiting effective heat transfer. At the same time, certain microorganisms also create corrosive byproducts during their growth. This growth can be controlled or eliminated by addition of biocides during the internal treatment process.

Fouling Fouling is a problem often encountered in the cooling towers, which refers to the process of attachment and growth of deposits of various kinds in the recirculation system. These consist of biological growths, suspended solids, silt, corrosive products and organic scales. Fouling is usually controlled by the addition of chemical dispersants, which prevent particles to form flocs, so that they can be kept in suspension.

Foaming Foaming problem is associated with the presence of biodegradable detergents, which creates foams in the distribution system. Foaming can be avoided by using anti-foaming chemicals.

Pathogenic organisms When reclaimed water is used, the assurance of adequate disinfection is a primary concern to protect the health of workers. The disinfection requirements for use of reclaimed water in industrial processes are made on a case-by-case basis. The most stringent requirement, similar to unrestricted reclaimed water use in food crop irrigation, would be appropriate if there exists a potential for exposure to spray. Protection of the neighboring public as well as plant operators is of prime importance.

Water Management Strategies for Industries

Water management strategies with the intention to (1) minimize water consumption, (2) minimize wastewater generation, and (3) minimize wastewater treatment costs can be broadly classified as internal strategies, external strategies and governmental policy. Internal strategies are those measures that are required to be taken at a factory level in order that water consumption and wastewater generation are controlled. These measures can be taken more or less independent of external strategies at a factory level, based on market-based approach.

While external strategies are measures that are required at the industry level, or are taken in the context of local or regional water management in industries. Generally, the factory management does not control these strategies although in certain cases some measures are required at factory level. The nature and number of a particular type of industry present in a locality or a region can significantly influence these strategies. Pollution control authorities in general formulate these strategies. Some of these strategies are summarized as follows:

1. Grouping of industries in a particular site (industrial parks) and having combined treatment methods and reuse policies
2. Rationing the water use within the industry and each process uses defined quantity of water
3. Reorganizing water use in different processes; efficient washing process (counter current washing, high pressure air rinsing, cascade circuit and others)
4. Using pneumatic or mechanical systems instead of using water for transportation (e.g., Poultry and food industries)
5. Applying economic instruments such as penalties, water charges, subventions, credits and grants
6. Process modification to minimize water consumption from open to closed systems of manufacturing process

Governmental water conservation policy is the key factor in water recycling and reuse in industries. Policy can be related to incentives for industry to promote internal recycling, implementation of economic instruments and discouraging effluent discharge through stringent standards (Hansen, 1989). However, in developing countries, industry is neither charged for water or wastewater services; nor are pollution control regulations adequately enforced. The concept of *Polluters Pay Principle* may be a good starting point. Compliance with stringent effluent requirements can force industries to implement new technologies to reduce effluent discharge. Higher charges for raw water could be applied to industries using large volumes of water and/or water with certain pollutants. Banning priority pollutants with significant health hazards also needs careful consideration. Examples can be seen in Singapore which levies a 15 percent water conservation tax on operations using more than a specified amount, and new factories needing more than 500 m^3 per month must apply for approval from City Council during the planning phase.

Given proper incentives, it is found that industry can cut water demand by 40 to 90 percent with existing techniques and practices. Economic incentives should be given to industry to comply with standards and policy and to reduce raw water intake and wastewater discharge. Incentives might consist of subsidies for industries implementing new and innovative technologies, financial and advisory support for industries funding new research. On the other hand, fines for non-compliance and closure for repetition of non-compliance can also signifiacantly achieve higher recycling and reuse. For example, a fertiliser plant in Goa, India cut water demand in half over a six year period in response to high water prices and government pressure to reduce effluent discharge into the sea, and dairy, pharmaceutical, and food processing industries in Sao Paulo, Brazil reduced water use per unit output by 62, 49 and 42 percentages respectively. (Kuylenstierna and Najlis, 1998). However, policies need to be fair, achievable, and enforceble in order that they can be supported by the industries on the challenges of sustainability to protect the public, the environment, and the natural resources.

Summary and conclusions

The rising costs of dependable water supply and wastewater disposal have increased the economic incentive for implementing water reuse and process water recycle in industries, worldwide. The purpose of water recycling and use is to: (1) supplement industrial water demand by reclaimed municipal wastewater (2) minimize industrial water consumption, (3) minimize wastewater generation, and (4) minimize wastewater treatment costs. The three major uses of water within industry are for heat dissipation, power generation, and processing. The scope of water recycling and reuse is highly dependent on the water quality requirement of the intended use and varies from industry to industry and from process to process. Among them, however, heat dissipation is one exception that is common to almost all industries. Thus, a concept of *cycles of concentration* with development of equations for water and salt balance in the recirculating cooling system was presented and discussed.

Management commitments and strategies on the challenges of sustainability are key to the implementation of successful water recycling and reuse. Various water management options can be broadly classified into internal strategies, external strategies, and governmental policy. The pollution control authorities decide governmental policies. Various types of incentives and penalties have found to bought impetus in water recycling and reuse. It is important**,** however, that the policies encourage market-based approach and need to be fair, achievable, and enforceable in order that they can be supported by the industries to protect the public, the environment, and the natural resources.

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