Resolving World Water Crises through Virtual Waterless Manufacturing

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ABSTRACT

As the world rapidly heads towards an imminent '*hydrocide'* caused by irresponsible human activity and billions cry for safe drinking water, enterprises are mass producing effluents as if wastewater was their main produce. No sane process could aim at avoidable effluent generation as an outcome of production. It is certainly the inadequate practices and insensitivity towards a seemingly abundant bounty of nature that led to the current scenario. The author spent about two decades evolving *Cleantech* as an innovative environment management approach towards source reduction of effluents in manufacturing industries now successfully demonstrated in over hundreds of industries. In all cases, significant emission cuts including zero emission in many cases have been achieved beyond compliance management with assured profits. Over the recent years, he made attempts to widen the scope of *Cleantech* from mere zero emission to include zero consumption of freshwater. By applying innovative process modifications and introducing improved set of manufacturing practices he has been able to demonstrate a new approach of *virtual waterless manufacturing* incorporating zero intake of freshwater and zero emission of wastewater. The concept has been successfully tested in a host of process industries including sugar, fruit processing, dairy and textile processing. In the current paper, the author has outlined the salient features of virtual waterless manufacturing as a scientific response to the oncoming global water crisis presenting exhaustive case studies of select process industries to establish a replicable general methodology and an inventory of replicable clean technology capsules universally applicable for similar manufacturing situations. With possible extension over a wider canvass of industrial activity and the visible multiplier effect, the concept holds a demonstrable potential to address the adverse impact of process industry on global water resources, saving the valuable resource and eliminating the cause of conflict between often competing water users like industry and communities.

Water is the most fragile of the finite resources much needed for the survival of the mankind. Given the potential for uptake, dispersal and mobility of contaminants, water resources could easily be singled out as most vulnerable in terms of fragility and susceptibility. Entry of pollutants anywhere in the water system affects all downstream situations irredeemable impact that continues gaining strength along the line of flow. No amount of remedial action could ensure total restoration and the only way to preserve the water quality and availability was to prevent over-exploitation and contamination of this 'finite' and 'non renewable' resource. Whereas preservation of water quality necessitates a 'zero emission' approach to prevent pollution, the quantitative aspects do call for a step further towards 'zero consumption'. Such an approach based on logical application of technological innovation and sound economic reasoning could make a dramatic change in the situation leading to pollution control at profit. Virtual waterless manufacturing is one such endeavor to ensure zero consumption of freshwater coupled with zero discharge of wastewater reducing the adverse impact of such activity on water environment to near zero. The concept if strategically leveraged to reduce pressure on water sources holds promise for protecting the global water resources and to eliminate ever prevailing conflict between competing water users like enterprises and communities.

Before understanding the concept of virtual waterless manufacturing, it is important to understand '*Cleantech*' as a strategic environ-management technique developed by the author for source reduction of pollutants in a process at source, through minor process modification, material substitution, improved manufacturing practices or low cost innovation, with a view to achieve low or no discharge, thereby eliminating the need for treatment. The concept is based on eco-efficiency principles and assures rapid payback on account of material savings, elimination of treatment costs, avoidance of liability costs and above all, improved corporate image and brand equity. Implementation of cleaner technologies and improved manufacturing practices in a manufacturing facility entails inherent advantages like easy passage to environmental certifications like the ISO 14000 EMS or Eco-labeling.

Cleantech is based on the principle of environment management beyond compliance with assured profit. It lays focus on management along the process lines instead of the conventional end of the pipe approach. It works on clear objectives of investment viability to provide the industry, a strategic competitive edge above the rest. The payback for implementation of Cleantech by the author in most cases varied between six months to a year and in many cases has been, as low as instant. For example, in case of a mushroom processing industry, wastewater originating from blancher when mixed with mushroom fleshing instantly converted into mushroom soup, a readily saleable product with zero investment, zero gestation and instant payback. In some cases, existing effluent treatment plants were abandoned as no longer required, while in most others, they could serve more efficaciously, as effluent loads reduced drastically. In most case, substantial energy savings were realized ranging from 15 to 35 percent, in an extreme case as high as 70 percent. A good number of industries in the red could bounce back merely through implementation of *Cleantech*.

Cleantech is not just confined to manufacturing or shop floor technologies. It has a great lot to do with the shop floor management practices, particularly the areas like house keeping, material handling/spill control, energy efficiency and waste handling. The entire concept is based on source segregation of wastes or effluent streams for specialized handling, reuse, recycling or disposal of each such stream. It would eventually lay heavy emphasis on apt deployment of separation technologies ranging from simple decantation, floatation, centrifugation, filtration, distillation, sublimation and evaporation to advance techniques like membrane technology, vacuum evaporation, freeze drying and super critical extraction. The concept also lays heavy emphasis on energy conservation and cleaner energy options. It also pays attention to areas like waste to energy along with emerging zero emission technologies and cleaner process alternatives.

The underlying principal of virtual waterless processing in the select industry is recycling invariably, but industries with highest potential for such close loop operation are essentially those with very high water content in the basic raw material. Further, industries deploying evaporation as process technique facilitate easy implementation of 'virtual waterless' processing. Elimination of harmful chemicals in processes to avoid contamination of condensate in process industries enhances the possibility of recycling in a close circuit. Over the recent past, the author has included product dematerialization and development of zero energy processes using innovative techniques like infra-red drying, microwave heating, low temperature processing, membrane dewatering and waste heat utilization including co-generation, thermal cascading and endothermic processing. Closing of water loop was integrated backwards to arrive at zero freshwater intake in processing industries like the sugar, fruit processing, dairy and textiles successfully. Some of the case studies on virtual waterless manufacturing are outlined below.

The technology of virtual waterless manufacturing involves innovative application of emerging processes, materials and practices for closing the water loop. Such measures vary significantly in terms of technological advancement, capital costs and degree of efficacy. However, the concept focuses principally on zero waste and is hence heavily oriented to self repaying economic viability. The techniques most efficaciously applied by the author include separation technologies ranging from centrifugal separation, decantation and vacuum separation to fractional distillation, membrane separation, freeze drying, freeze concentration, liquid chromatography and super critical CO_2 extraction. Hazardous chemical processes like chlorine bleaching, biocide disinfection and sterilization have been accomplished using ozone as an alternative while innovative practices still occupy the lead role of inexpensive initiatives with significant impact. It may be noted that the technique really finds best application as retrofit measures in the developing world scenario where investment in environmental technologies is particularly shy. In such economies, it offers the enterprises an easier and attractive option for low cost modification of existing facility for instant compliance and sustained competitive advantage.

Case study of a virtually waterless milk processing industry

Despite the inherent high water content in milk, most processors globally discharge between 2.5 to 3 liters of wastewater per liter of milk processed. The freshwater intake of most dairies is as high as 2 liters per liter of milk processed. A typical milk processing industry with capacity to process 500,000 liters of milk per day was studied to work out a "zero in-zero out' package. The company bought 1000,000 liters of fresh water daily and generated about 1400,000 liters of wastewater that could not be treated to desired standards. The company was producing milk powder, casein, whey proteins and lacto sugars resorting to extensive use of hydrochloric acid and caustic soda during the process. Large quantities of detergents and toxic disinfectants were also deployed for sanitation. After a '*Cleantech*' audit major initiatives suggested for freshwater reduction included the following;

- Housekeeping measures including spill control and pressure jet washing resulted in reducing the fresh water consumption by about 100,000 liters per day.
- Setting up a cold chain for collection of raw milk to eliminate the use of alkali for preservation.
- Recycling of entire condensate (Approximately 400,000 liters/day) to substitute for freshwater consumption.
- Isolation of wastewater streams for individual treatment and recycling options.
- Alternative dis-infection measures like cold ozonation to substitute or supplement conventional pasteurization leading to substantial energy saving and superior product quality.
- Elimination of detergent from CIP system and use of ozonated condensate for CIP to save about 60,000 liters per day.
- Air dis-infection in storage area by ozonation to prolong product shelf life, improve product quality and eliminate toxins.

It was observed that low investment options of immediate nature could reduce the freshwater intake from an average of 1000,000 liters per day to a level of about 450,000 liters per day that meant a reduction by 55%. Modification of CIP system as proposed could promise a reduction by another 100,000 liters per day that accounted for about 10% of the total freshwater intake ensuring elimination of harmful chemicals & detergents. Alternative cold sterilization process based on ozonation could not only ensure high product quality and longer shelf life, but also help preserving valuable immunoglobulin that usually gets destroyed in the conventional pasteurization process. Measures implemented so far resulted in potential saving of 70% on freshwater consumption, reducing the inflow of wastewater into treatment facility by almost 80%. Complete recycling of condensate using membrane technology and cascading water use as per quality classification are likely to yield an ultimate reduction of well above 95% over a period of time making it a virtual waterless process with near zero emissions. Future initiatives in view include membrane concentration of skimmed milk and impulse drying of milk fractions using advance technology impulse dryers ensuring well above 40% saving in energy requirements for the drying process, assuring drastic cost reduction and substantially lower requirement of steam.

Case study of a virtually waterless sugar mill

Sugar manufacturing involves extensive processing of cane juice with high water content of above 80% depending upon the extraction techniques and practices in individual mills. Yet, sugar manufacturing ranks amongst the largest water guzzlers. The process and materials are not highly polluting in nature, yet, the prevailing practices give it an image of highly polluting industries generating large quantities of diverse wastes for disposal. The industry due to large economies of scale has large inertia to resist change and the pace of technological up-gradation and modernization has been rather slow. The location of industry is by and large in far flung rural segments with weaker infrastructure and traditional workforce and the management practices and attitudes are far too conservative to strive for a change for the better. The technological change is initiated by few and adopted by the rest at amazingly slow pace. Even the equipment manufacturers and designers show lack of initiative on account of large initial investment and lukewarm response from the industry. Although, last three decades have witnessed considerable progress in areas like co-generation, energy efficiency and productivity, sugar industry on the whole remains notorious for waste generation, water consumption and environmental pollution.

The evolution of virtual waterless manufacturing module for the sugar industry owes its origin to the *Cleantech* experiments for innovation based zero emission oriented process re-engineering adding the extra dimension of zero freshwater consumption. *Virtual waterless manufacturing* could be formally defined as such manufacturing activity or technique, as may involve or aim at *zero freshwater* consumption as well as *zero wastewater* discharge based on usual principals of *Cleantech*. Examples of such industries include essentially those with substantial content of inherent water in raw materials, like cane sugar manufacturing, fruit processing and dairy industries. Deeper research however established the universal applicability of the concept to include metal powder metallurgy and surface treatment industries using the electron beam technology and the vapor deposition technologies respectively for surface treatment. Recent advances in super critical extraction technology and equipment, particularly the advent of super critical CO_2 extraction have led to very versatile absolute waterless manufacturing opportunities in the textile, food processing and phyto-chemical industries. Before embarking upon the virtual waterless manufacturing approach for environmental management of sugar manufacturing industry, the noteworthy ailments characterizing the sugar industry were diagnosed as follows.

- High freshwater consumption
- High wastewater generation
- High solid waste generation
- Significant air pollution potential
- Wasteful processing & practices
- Use of harmful chemicals & biocides
- Very low diffusion of technology
- Conservative management
- Low investment in R&D
- Poor initiative for human resource development
- Large economies of scale
- Investment constraints for technology up-gradation
- Irresponsible attitude towards water as a user
- Artificially low cost of water as a resource

Innovative processes and materials were used to arrive at environmentally preferred alternative routes of manufacturing for zero emission and zero freshwater intake. These included techniques like condensate recycling to reduce freshwater consumption, reuse of water streams for specified low caliber use, recycling of treated wastewater using membrane technology and ozonation, elimination of sulfitation using low temperature membrane processing and eliminating the use of biocides using alternative sanitation techniques. Results reflected in zero freshwater consumption, environmental management beyond compliance and organic sugar production qualifying an eco-mark.

In the specific case under reference one sugar mill was taken up for process re-engineering to achieve 'zero entry- zero exit' by closing the water circuit. It was observed that the industry was running seven tube-wells round the clock to draw 15000 cubic meter of fresh water to process about 12000 metric tons of sugar cane every day. This was amazing as sugar cane juice contains over 85% water and that evaporation is the main process involved in the manufacture of sugar. A quick survey of the sugar industry within India and around the globe indicated a similar phenomenon with varied degree of freshwater destruction globally in vogue.

A cursory water balance analysis could reveal that sugar manufacturing is theoretically net water generating process rather than a water-consuming affair. The opportunities for reducing fresh water consumption to zero level ranged from seemingly easy options like recycling the condensate to those including reduction of contaminants like sulphates, chlorides, organic colorants, toxic biocides, oils and greases to completely recycle the water streams. The surplus water still leftover after minimizing the freshwater consumption offered the challenge of a perfect treatment for supply as fresh water to meet civic requirements. The measures identified ranged from simple housekeeping practices to reduce the freshwater consumption to prevention of vapor carry over into the condensate through equipment modification. Extensive application of separation and treatment technologies for individual water streams was required to eliminate pollution at source. Such measures could be easily classified into immediate, short-gestation and long-term measures depending upon the time and resources required. It is significant to observe that the immediate and essentially low cost measures already implemented could result into sealing out five out of the seven tube wells, thus reducing the fresh water consumption by almost 70% to a low of about 4500 cubic meters per day, thus saving about 10500 cubic meters daily. Further reduction required investment-oriented options like setting up in process 'kidney' units to recycle isolated water streams.

Medium/long term measures include major process modifications like elimination of toxic biocides from mill sanitation and other harmful processes like juice sulphitation to ensure a safe organic product and eliminate contamination of water. Futuristic options include extensive application of the membrane technology and ozone treatment for complete elimination of color, toxins and bacterial infection. The preventive measures start with organic farming and end up using baggasse charcoal for cost effective water treatment including co-generation of power. The zero emission measures end up with the ultimate recycling of treated effluent for colony and other mixed civic needs.

Virtual Waterless Manufacturing initiatives in textile dyeing & processing

Scattered implementation of cleantech modules was undertaken in various textile dyeing and processing industries. In case of one industry dyeing threads of various colors, it was observed that large quantities of colored effluent were generated whenever there was a switchover to a new shade as the equipment was to be rinsed each time before a changeover. The orders in hand were scrutinized to find out available loading for each color. Interestingly, it was found that out of the 24 machines, there was sufficient single color loading available for about 14 machines round the clock. The production schedules were simply recast to dedicate one machine for each color. Another two machines were dedicated to black color. This eliminated the need for changeover for 16 machines instantly. These machines were further modified to make a close loop for complete recycling of hot dye-bath so as to eliminate wastewater generation, reduce dye consumption to replenishment levels and save process heat. Low effluent generation was thus restricted only to eight machines reducing total effluent quantity by almost 85%. As a measure of ultimate innovation, all colored releases along with any other sporadic spills were mixed with the black dye to get rid of the entire effluent saving money on the cost of dye as well as on treatment of wastewater. Another experimental initiative involved textile dyeing using super critical carbon dioxide as solvent. The liquid CO2 on gasification did not retain dyestuff resulting into 100% transfer of dye while gas could be recycled after re-compression with no liquid effluent released. The process also holds promise for saving energy for drying thus reducing costs and cutting down air emissions. Detergent free cleaning of fiber using electrically charged water combined with ultrasonic agitation has since been commercialized widely.

Future perspective

Virtual waterless manufacturing is a rather recent concept promoted by the author that found wider acceptance in India, Thailand and Japan. The author has used a wide variety of emerging technologies to achieve waterless manufacturing in a wide variety of industries in close association with Professor Saburo Matsui of Kyoto University who is a renowned international expert on water technology. Apart from the three distinct case studies of sugar mill, dairy and textile processing cited above, the author experimented extensively on fruit processing industries, pharmaceutical industries, phyto-chemical industries and so on with varied degree of success. Some of the interesting examples of such initiatives include fruit pulp dewatering using membrane systems as an alternative to thermal evaporation or use of super critical $_{CO2}$ extraction as an alternative to conventional steam distillation or solvent extraction or revival of explosion pulping for manufacture of fiber board or detergent free cleaning using electrically charged water and so on. A number of technology modules of replicable nature have been standardized for wider application around the globe. The author as a firm conviction makes no claims on intellectual property aspect of alternative processes developed so that they could be freely used by the global community on no profit basis to mitigate the adverse environmental impact of human activity on our global environment. Replication of virtual waterless modules globally could save millions of cubic meters of freshwater each day to resolve the global freshwater crises effectively on sustained basis. This would also revolutionize the economic and ecologic performance of enterprises beyond compliance reducing pressure on scarce global resources particularly freshwater.

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