Water Reuse in Industrial food Processing

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Abstract

While water, as an industrial commodity, is considered increasingly as a valuable material and the subject of responsible care for the environment, water reuse is increasingly regarded as a tool for substantial reduction in water supply needs, and saving in related costs.

A strategic approach to water reuse must be based on a systematic analysis and on the principle that any water user must never use more water of a higher quality than strictly needed.

In this paper some hints are given for implementing water reuse in the food processing industry, particularly referring to the practical case of tomato processing for which a case study is also reported.

The results clearly show how remarkable environmental and economic advantages can be simply obtained by implementing low investment cost solutions, and that water supply and discharge flow rates can be dramatically reduced without implementing any special water upgrading treatment process.

Introduction

Water is a valuable resource, essential for life, but not easily renewable, and it has high purity requirements for human feeding. High purity water is becoming more and more difficult to find in the environment, so that it is becoming available at higher and higher costs. Industry is increasingly competing with other water supply needs for community purposes.

Water as an industrial commodity then, must be increasingly considered as a valuable material, and the subject of a rational and systematic approach for its careful use.

In a strategic perspective the principle to be applied, is that any water user must never use more water of a higher quality than strictly needed.

To meet this target the industry has to implement a general and systematic approach to water reuse, based on knowledge already available from various reuse practices, up to now performed without a systematic view of the problem.

The problem of rational use of industrial water is still partly neglected by industrial management, either because it is considered a worthless ancillary to other industrial production factors, or because an overall and integrated view of the problem is lacking.

In this paper some hints are given for a systematic approach to the problem, particularly referring to the practical case of tomato processing industry for which some typical data are also reported.

A Systematic Approach

Knowledge obtained from different previous applications of water reuse experienced in industrial facilities may be used to define a general and systematic method to approach the problem. This method can be applied in all practical situations, up to the ultimate case of total recycle with zero discharge.

The method is accomplished through three subsequent steps:

- .Categorizing of waters directed to every single user, including definition of purity standards for every category;
- Categorizing of waters from every single user, including definition of treatments to re-qualify water for recycle or discharge and economic balance;
- Water mass balance (both global and detailed for every user) with listing of users by categories.

The three steps are described in the following:

1. Categorizing of waters to users

Uses of water in an industrial process are extremely diversified. It is therefore necessary to gather the various water types in categories, each of them are defined by quality standards that make them usable for several applications.

An excessively high number of categories (so high as to identify a water standard for every single use) is not generally useful, except in the case of very large mass flow rate or exceptionally high purity required.

Generally speaking industrial waters are divided into five categories:

Boiler water;
Process water;
Drinking water;
Cooling water;
Service water.

Water belonging to each category is defined by specific purity standards. The categories listed above are sorted by decreasing purity standard requirements related to undesirable or non admitted pollutants.

Purity standards for process, cooling and service waters may vary significantly from one process to another. Standards for boiler and drinking waters are usually submitted to general regulations.

2. Categorizing of waters from users

Different types of water coming from every user must be classified in order to obtain a reasonable number of categories. These are generally defined according to the following **table 1**.

	Concentration of inorganic salts	Concentration of organic substances
A	Low	Low
B	High	Low
C	Low	High
D	High	High

Every single water-from-user category, must be evaluated in order to identify eventual economic advantage in upgrading water, to a quality standard that meets requirements of a water-to-user category. Upgrading must be considered on the basis of minimum treatment required for obtaining standard water for reuse in the appropriate water-to-use category or for discharge.

The entity of reuse that can be economically performed is identified, together with global water supply requirement and users distribution.

Priority is given to those systems where internal reuse or direct reuse in the following unit operation in the process is possible.

A deeper investigation is required to identify possible reuse paths between different process units, or where complex upgrading treatments are needed.

Closed loop utilization of water may give increasing degradation of its quality due to accumulation of pollutants. Higher quality water must generally be added while a side stream is extracted.

For every reuse water stream added to the water flow-sheet, the water streams list must be properly modified deleting inlet and outlet streams, and eventually adding make-up streams.

3. Water mass balance

The water mass balance is written on the basis of the water streams list including inlet and outlet of every user. It also contains data concerning mass flow rates, distribution, supply and discharge systems.

Supply streams are classified by category and mass flow, discharge streams by mass flow and pollutants concentration. Quality data generally include pH, suspended solids, total ion concentration and total organic carbon concentration, but depending on the specific application being considered other data may be included, i.e., concentration of specific ions or specific organic compounds.

The mass balance will not be closed because of loss from evaporation, leakage and eventually consumption in chemical reactions. Global inlet mass flow rate will always be higher than outlet mass flow rate. Therefore a make-up inlet stream will be necessary also in the case of total reuse (zero discharge).

It may occur that an outlet stream from a user has standard quality for inlet into another user without any treatment. In this case related mass flow rates correspond to the minimum reuse to be considered.

Reuse Optimization

Referring to the flow sheets reported in fig 1.a and 1.b one can identify the different cost elements that affect the overall water supply cost.

The most relevant cost elements related to reuse are:

- water upgrading treatments (investment + running);
- pumping P_2
- pumping P_1
- inlet water supply;
- water discharge
- treatment prior to discharge.

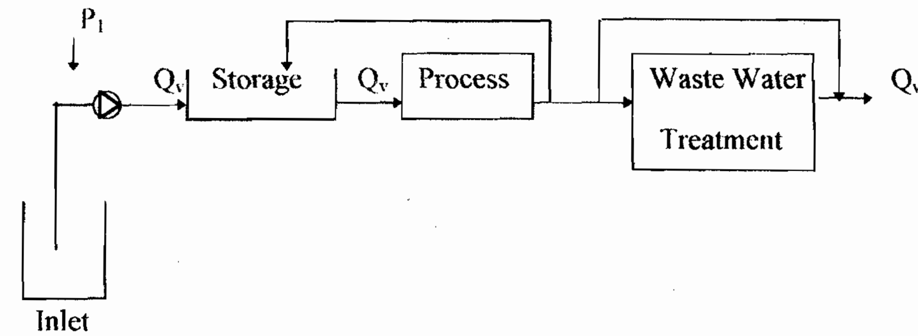
Case 1: New Plant

In the case of a newly built plant the overall yearly cost (OYC) related to the flow sheet in fig. 1.b (partial water reuse) can be written identifying every single cost element:

a) reused water upgrading cost investment by assuming investment cost as a function of upgraded water mass flow rate:

$$K_T = \alpha(Q_v.R)^\beta \qquad (1)$$

Fig 1a. Open loop flow sheet, toal discharge



running costs

depending on running time:

$$C_T = (Q_v.R).t.r_t \qquad (2)$$

b) pumping cost P_2

Investment

$$Kp_2 = \varepsilon.P_2^\delta = \varepsilon.B_2^\delta.(Q_v.\text{-}R)^\delta \qquad (3)$$

running costs

$$Ce_2 = B_2.(Q_v.R).t.r_e \qquad (4)$$

c) Pumping cost P_1

Investment

$$Kp_1 = \varepsilon.P_1^\delta = \varepsilon.B_1^\delta.(Q_v.(1-R))^\delta \qquad (5)$$

running costs

$$Ce_1 = B_1.(Q_v.(1-R)).t.r_e \qquad (6)$$

d) water supply

$$Ca = Q_v.(1-R).t.r_a \qquad (7)$$

e) exhaust water discharge

$$Cs = Q_v.(1-R).t.r_s \qquad (8)$$

f) discharged water treatment plant cost

$$Kd = \alpha.(Q_v.(1-R))^\beta \qquad (9)$$

The latter cost element can be generally neglected in this optimization study, considering that every water stream is treated in the existing treatment plant(s) either to reduce pollutant concentration to the subsequent upgrading operation or to discharge water.

On this basis, the Overall Yearly Cost can be defined as:

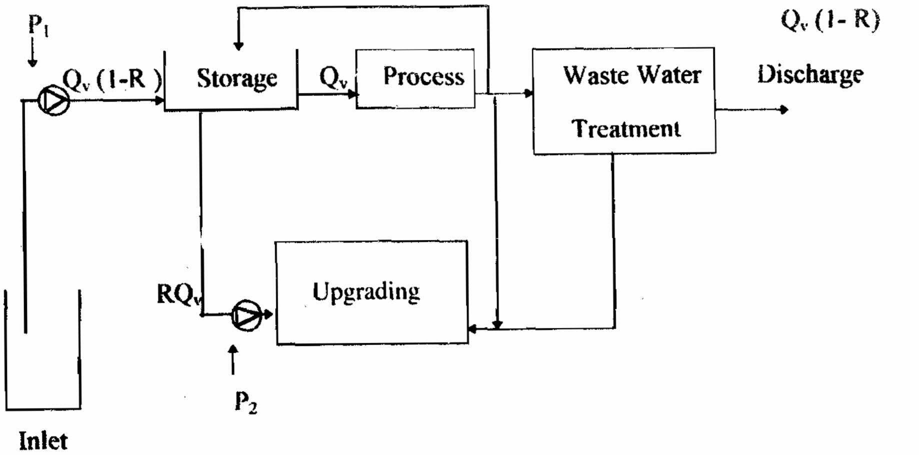
$$OYC = f_1.K_T + f_2.Kp_1 + f_3.Kp_2 + Ct + Ce_1 + Ce_2 + Ca + Cs \qquad (10)$$

Symbols in the previous equations mean the following:

f_1, f_2, f_3 = mortgage coefficients for equipment (commonly $f_1 = f_2 = f_3 = f = 0.1$ for depreciation in 10 years);

Qv = Water (inlet + upgraded reuse) mass flow rate (m^3/h);

Fig 1b. Closed loop flow sheet, partial discharge.



P_1, P_2 = pumps power (kW);
B_1, B_2 = coefficients for the pumps:

function of pressure and defined as:
$B_i = \gamma.H_i/3600.\eta.75$ (kWh/m³);
t = Workhours/ year (h);
r_e = power cost (£/kWh)
r_a = inlet water cost (£/m³)
r_t = upgraded water cost (£/m³)
r_s = water discharge cost (£/m³)
R = upgraded water reuse ratio.

By substituting the expressions (1) - (8) in equation (10), one obtains;

$$OYC = f.(\alpha.Q_v^{\beta}R^{\beta} + \varepsilon.Q_v^{\delta}(B_2^{\delta}R^{\delta} + B_1^{\delta}(1-R)^{\delta})) + Q_v(R(r_e(B_2 - B_1) + r_t - r_a - r_s) + r_eB_1 + r_a + r_s) \quad (11)$$

The best technical-economical solution is obtained by minimizing the function above, i.e., by equating:

$$\frac{\partial OYC}{\partial R} = 0 \quad (12)$$

From equation (12) one obtains the optimum value for R, i.e., the water reuse ratio that minimizes the overall water cycle cost. R ranges from 0 to 1. When it approaches zero water reuse is not economically attractive. When its value is near to unity water recycle should be used to the maximum possible extent.

The solution must be obtained numerically in most practical cases, but some simplified cases can be simply described. Examples are reported in the following.

1. The scale factor is approximately the same for every equipment.
In this case we have $\beta = \delta$, and then:

$$R^{\beta-1}.(\alpha+\varepsilon B_2^{\beta}) - \varepsilon B_1^{\beta}.(1-R)^{\beta-1} = \frac{t}{\beta f Q_v^{\beta-1}}(r_e(B_1-B_2) + r_t - r_a - r_s) \quad (13)$$

2. Running costs are negligible.
This is the case when investment costs are particularly high or when: $B_2 = B_1$ and $r_t = r_a + r_s$. The former equation reduces in this case to:

$$R^{\beta-1}.(\alpha+\varepsilon B_2^{\beta}) = \varepsilon B_1^{\beta}.(1-R)^{\beta-1} = A \quad (14)$$

This can be expressed graphically as in **fig. 2**, identifying optimum R.

3. Pumps power is negligible.
In this case $B_1 = B_2 = 0$ and, being $\beta<1$, equation (13) becomes:

$$R = \frac{1}{Qv}.\left(\frac{\alpha\beta f}{t(r_t - r_a - r_s)}\right)^{1/1-\beta} \quad (15)$$

Case 2: Existing Plant

When considering an existing plant the break-even point can be identified, that is the minimum R value that makes additional costs paid for implementing reuse equal to benefits from water saving. Cost elements are, in this case:

- upgrading treatment costs (including pumping P_2);
- reduced pumping cost P_1;
- Savings on inlet water;
- Savings on outlet water.

The equation for this case becomes:

$$R = \frac{1}{Qv}.\left(\frac{n\alpha}{t.(B_1r_e + r_a + r_s - r_t)}\right)^{1/1-\beta} \quad (16)$$

Where n is number of years for payback.

Case study: Tomato processing Industry

The water streams in a tomato processing industry were classified following the previously discussed concept of gathering process water streams in homogeneous categories suitable for proper uses. Secondly global input and output material were identified as:

In	Out
Tomato	Tomato juice
Water	Seeds, peel
Fuels	leaves, soil
	water

Every unit operation in the process has been then evaluated considering water mass flow rate needed. The water flow sheet is reported in **fig 3**.

Water streams in tomato processing are represented by washing water, carrier water for raw tomatoes (both included in "pre-treatment"), process water, cooling water for cans and sterile line, water from condensation of steam from product

Fig 2. Optimum R for case 1.2

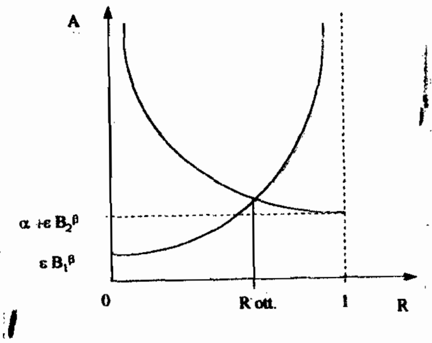
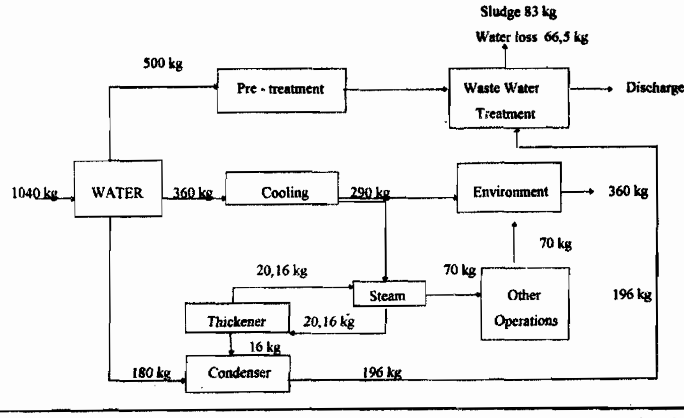


Fig. 3. . Actual flow-sheet



thickening, water for washing of plants, rooms and pavements. Pollutants are in any case organics (generally biodegradable). Parameters to define pollution are, then: BODs, COD, settling solids, suspended solids, NH nitrogen..

Therefore water to be treated is submitted to solid-liquid separation followed by activated sludge biotreatment. The effluent is then input to a settler for separation of activated sludge which is afterwards centrifuged and disposed of.

For every 100 kg of processed tomato 0.5 m^3 of waste water are sent to the waste water treatment plant. Water used for cooling cans (0.25 m^3) is simply discharged without treatment. Only a part of pure water used for cooling of the sterile line (0.07 m^3 versus a total amount used of 0.11 m^3) is reused for steam production.

To define water mass balance the water streams list previously defined is used by characterizing every stream by quality and mass flow. Quality parameters are pH, suspended solids concentration, soluble salts concentration and COD. Global mass balance referred to 100 kg of processed tomato is:

Process STEP	Water demand
Pre-treatment	0.5 m^3
Cans cooling	0.25 m^3
Sterile line cooling	0.11 m^3
Condenser	0.18 m^3
Water from thickener	0.016 m^3
Total	**1.056 m^3**

A reduced overall water consumption is possible if in-process reuse is performed, based on water quality requirements. This may require upgrading to be performed on water prior to reuse.

To optimise water reuse the following four categories were selected:

- water from pre-treatment;
- water from thickener (including water from condensation of steam from both the product itself and heating);
- cooling water
- water for the steam generation

The former two categories are both suitable for use as pre-treatment water after the standard waste water treatment. Quality standard required is absence of pathogen microorganisms (i.e., *Escherichia coli*), related to biological safety of the product. Drinking grade water is not indeed required.

Cooling water is not degraded in use, therefore no upgrading is needed. Its quality standard is related to low carbonic ion content and microbiological grade suitable for the pre-treatment step subsequent to the cooling step. It must also be suitable for steam production. No treatment is definitely needed and therefore reuse is obviously attractive in that is allows savings both on supply and on waste water treatment.

Pre-treatment (carrier water + washing): most of the water used in the process is connected to this operation. Exhaust water from the operation has a high content of suspended solids, organic matter and bacteria from the soil. By its nature the soil particles forming the suspended solids are easily separated by settling. Water from washing contains the same pollutants as carrier water, in a lower concentration so that it can be used subsequently as the carrier with no treatment (counter-current with the process stream). Increasing the performance of the settling process for upgrading of the outlet water requires increasing residence times and treatment costs increase more than linearly for higher purity standards. Therefore inlet of some make-up water is convenient and it was demonstrated that an optimum value exist for make-up water inlet flow rate equal to 20% of total mass flow rate used in the operation (i.e., 0.5 m^3/ 100 kg tomatoes).

Cooling water: this operation involves a water demand of 0.11 m^3 / 100 kg tomatoes in the sterile line + 0.25 m^3 / 100 kg in the can line. Actually the stream from the can cooling is disposed of, while the stream from the sterile line is partly (0.07 m^3 / 100 kg) reused for steam production and partly (0.04 m^3/ 100 kg) discharged. It is proposed to reuse the fraction actually discharged by returning it to the primary storage with no treatment.

Condenser water: water used for heat exchange in the condenser (0.18 m^3 / 100 kg) together with a smaller stream (0.016 m^3 /100 kg) from condensation of extracted water is actually discharged after proper treatment to satisfy regulatory limits. It is proposed to reuse it after the same treatment by returning it to the secondary storage tank to be subsequently used for washing and carrier.

By implementing the reuse procedures described above actual water demand of the facility can be reduced from 1040 m^3/ 100 kg to 260.5 m^3/100 kg.

The proposed water flow-sheet is reported in **fig 4.**

Key water mass flow rates for the actual situation and the proposed alternative are resumed in the following table.

Water (Kg/100 kg)	Actual	Proposed
total inlet	1040	260.5
reused	90.16	869.66
used in process	1130.16	1130.16
produced	16	16
discharged after treatment	696	206.5
discharged without treatment	360	70
Total outlet	**1056**	**267.5**

From these data the following indexes can be calculated (I and I' in Kg water used/ kg tomatoes processed; IRT and IRD in

Fig. 4. Proposed flow-sheet