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To cite this article: C Zaharia 2017 *IOP Conf. Ser.: Mater. Sci. Eng.* **227** 012138

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Comparative overview of primary sedimentation-based mechanical stage in some Romanian wastewater treatment systems

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Abstract. Nowadays, wastewater (WW) treatment facilities are considered significant exposure pathways for solid particles, and also significant concerns of any quality conscious manufacturer. Most solid particles have some forms of organic coating either used as active material or to suspend and/or stabilize different present solid materials, having increase in toxicity that must be reduced, or sometimes even totally eliminated, especially if effluent is either discharged directly to surface water, or distributed through industrial water supplies. Representatives providing innovative technologies, comprehensive supports and expertise in wastewater and sludge treatment field are known, each one using modern treatment technology and facilities. Mechanical treatment is indispensable in primary treatment steps of both municipal and industrial WW applications, its main goal being separation of floating, settling and suspended materials (especially into a primary sedimentation-based treatment step).

The aim of this work is to present comparatively the performance in solids removal of conventional mechanical WW treatment stages, especially those based on primary sedimentation, or sedimentation-like operations applied for Romanian urban WW treatment plants (serving two towns with ca 18,000 inhabitants), industrial WW treatment plants (deserving industries of vegetal food processing and organic chemicals' manufacturing) and additional information on valorisation of separated solid material and improvement possibilities.

1. Introduction

In actual times, water quality management (associated with subareas of water and wastewater treatment) is a society necessity and obligation rather than an optional undertaking. As society structure becomes more complex, water quality requirements, produced wastes, management systems and tools, and environmental impact due to wastes (gaseous, liquid-as-WW, solid) become greater in complexity, subtlety, and magnitude [1], [2]. Modern society is centred closed to an industrial city, where wastewaters (WWs) flow is generally large and discharged in a complex sewer system, and/or emisar after its corresponding required treatment. Industrial processes produce often WWs that are toxic to many forms of living organisms. Therefore, the modernisation and sophistication of present society has resulted in production of larger quantities of WWs that are more concentrated and potentially harmful to receiving aquatic environment.



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Most polluting compounds in a river water, monitored in upstream and downstream (strategic controlling points/sections) of a WW treatment plant (WWTP), were found to enter by periodic or accidental discharges, mainly as particulate matter (e.g. mineral materials and metals, or different organic compounds adsorbed onto suspended solids) and dissolved residuals.

Modern wastewater (WW) treatment should be aimed at the protection of waters and environment, therefore domestic WW is collected usually in sewer systems and treated within a central WW treatment plant (CWWTP), and industrial WW is treated frequently at source within a decentralised WW treatment plant (DWWTP), or central on-site industrial WW treatment plant (CWWTP). Most frequent approaches to WW treatment are consisting of: (i) centralised WW treatment, normally using a CWWTP; (ii) CWWTP, with pretreatment at source of upstream tributary stream; (iii) WW discharge into a municipal WWTP; (iv) WW discharge into a municipal WWTP with on-site pretreatment at source, and (v) decentralised WW treatment facilities, treating effluent at source and discharging it into emisar (no central WW treatment facility on-site) [1].

More sensible from ecological and economical point of view is to treat WW as close as possible to its source and without need to construct extensive and often expensive sewer systems. In addition, the WW problem is a worldwide concern and solutions frequently need to be easy and quick to implement, affordable and adaptable to allow for tailored solutions to be offered [2].

In most cases, the requirement and necessity implies DWWTP as most recommended solution. Current concept of Decentralised Sanitation and Reuse (DeSa/R) [3], [4] relates to the methods of decentralised WW treatment that provide for the reuse of treated WW in the technological process and/or reuse of WW nutrients.

Continuous population growth imposes huge amounts of irrigation water for agricultural land, and also use of common fertiliser resources that can be: (i) mechanically treated nutrient-containing WW, after disinfection, used for irrigation purposes without any preceding separation need, or (ii) fertilisers extracted from urine and grey water collected separately (WW from showers, wash basins, bathtubs, washing machines).

After intermediate storage, the separated WW flows (known as yellow, brown and greywater flows) are each directed to specific treatment facilities where fertiliser, biogas, humus and service water are produced. Loaded rainwater is also treated to enable it to be suitable for groundwater regeneration, or industrial process water demand. Industrial WW is different from municipal WW (in composition, flow, required treatment facilities), and consequently individual industrial sectors (table 1) need individual WW treatment solutions (table 2).

The terms as *preliminary*, *primary*, *secondary*, and *tertiary WW treatment* (Figure 1) have become and still are synonymous with screening and grit separation, primary sedimentation (without or with coagulation-flocculation process), biological treatment with secondary sedimentation, and removal of residual or non-biodegradable materials by any means (advanced oxidation, adsorption, membrane processes, precipitation, ionic exchange), respectively. In case of domestic wastewaters and not only, *primary treatment* removes 40% of COD-Cr, 35% of BOD₅ and 60% of suspended solids, whereas *secondary treatment* removes an additional 50% of the incoming COD-Cr, 80-90% of BOD₅ and an additional 33% of suspended solids [5]. As consequence, it needs *advanced wastewater treatment* functioning for short periods, because of increasing control cost problems [6].

Table 1. Wastewater treatment technology for different industries.

Industry Sector	Treatment process solutions
<i>Slaughterhouses / meat processing</i> (cattle, pigs, poultry) – <i>slaughtering</i> <i>and processing</i> (ready-to-eat products)	<ul style="list-style-type: none"> - Fine screening (> 1 mm); - Course screening (> 6 mm); - Dissolved air flotation; - Filtration; - Paunch manure press; - Cattle truck washing

<i>Breweries/ breverage industry</i> (breweries; maltheuses; bore holes and wells; fruit juice production)	<ul style="list-style-type: none"> - Screening; - Biological sludge treatment; - Filtration; - Membrane bioreactor
<i>Food industry</i> (confectionary industry; delicately/bakery products) or fish industry	<ul style="list-style-type: none"> - Screening; - Dissolved air flotation; - Sludge treatment; - Filtration; - Biological treatment with membranes
<i>Food industry</i> (fruit juice concentrate; canning industry; potato processing)	<ul style="list-style-type: none"> - Screening with grit trap; - Biological sludge treatment; - Filtration; - Biological treatment with membranes
<i>Dairy industry</i> (dairies; cheese dairies; butter production; yoghurt production)	<ul style="list-style-type: none"> - Screening; - Grit/grease trap; - Dissolved air flotation; - Flotate sludge treatment; - Biological sludge treatment; - Biological treatment with membranes
<i>Paper industry</i> (waste paper recycling; pulp mills; WWTPs; fresh water conditioning)	<ul style="list-style-type: none"> - Coarse material / sediment separation; - Grit separation; - Sludge / coarse material treatment; - Fibre recovery; - Process water treatment; - Filtration of suspended material
<i>Chemical and petrochemical industry</i> (e.g. pharmaceutical industry; fertilizer production; refineries)	<ul style="list-style-type: none"> - Production sludge treatment; - Cooling and/or process water treatment; - Foreign matter separation from liquid media; - Sediment / Sludge thickening and dewatering
<i>Building industry and building material suppliers</i> (gravel production; prefabricated parts production; concrete production)	<ul style="list-style-type: none"> - Grit separation; - Process water recycling; - Sludge thickening and dewatering; - Coarse material separation; Screening up to 0.2 mm bar spacing; - Filtration; - Biological treatment with membranes

Table 2. Wastewater (WW) treatment operations and processes used in conventional WWTPs.

Treatment scope/ target	Treatment operation / Process	Observations / Comments
Suspended solids removal	Sedimentation (Preliminary / Secondary) Filtration: - Depth; - Precoat	Common use in domestic and industrial WW treatment
Turbidity removal	Coagulation / Flocculation Sedimentation Filtration	Often used for industrial WW treatment, and rarely for domestic WW treatment
Dissolved-solids removal	Precipitation / Ion exchange Filtration	Often used to remove hardness and other metals
Dissolved-	Distillation / Reverse osmosis	Use to reduce total dissolved solids (TDS)
Dissolved-	Bio-oxidation with activated	Usual activated sludge used in suspended

organic removal	sludge (aerobic or/and anaerobic systems) Secondary sedimentation	form in WW mass (static regime) or as membrane (dynamic regime); need of efficient aeration systems and S/L separation
	Activated adsorption	carbon-based Usual use for industrial water treatment, industrial secondary (before biological stage) or tertiary (finishing and removal of residual organics and inorganic species after biological stage) WW treatment; adsorption of refractory organics
	Chemical oxidation	Chlorine, ozone, Fenton-like reagents with hydrogen peroxide, persulphate, UV-irradiation, TiO ₂ /M _x O _y -based heterogeneous oxidation/UV photo-oxidation, used to oxidize organics
Microorganism growth stimulator (nutrients) removal	Advanced (tertiary treatment) by precipitation, membrane processes, adsorption, advanced oxidation coupled with adsorption, reverse osmosis	High removal of total nitrogen and phosphorus content in all urban WW treatment plants in Romania
Cooling	Cooling towers	Thermal pollution concerns of receptors
Disinfection	Chlorination	Most common method used in Romania
	Ozonation	Effective, no residual products formed, but more expensive than chlorination
	UV irradiation	Methods used especially for low WW flows

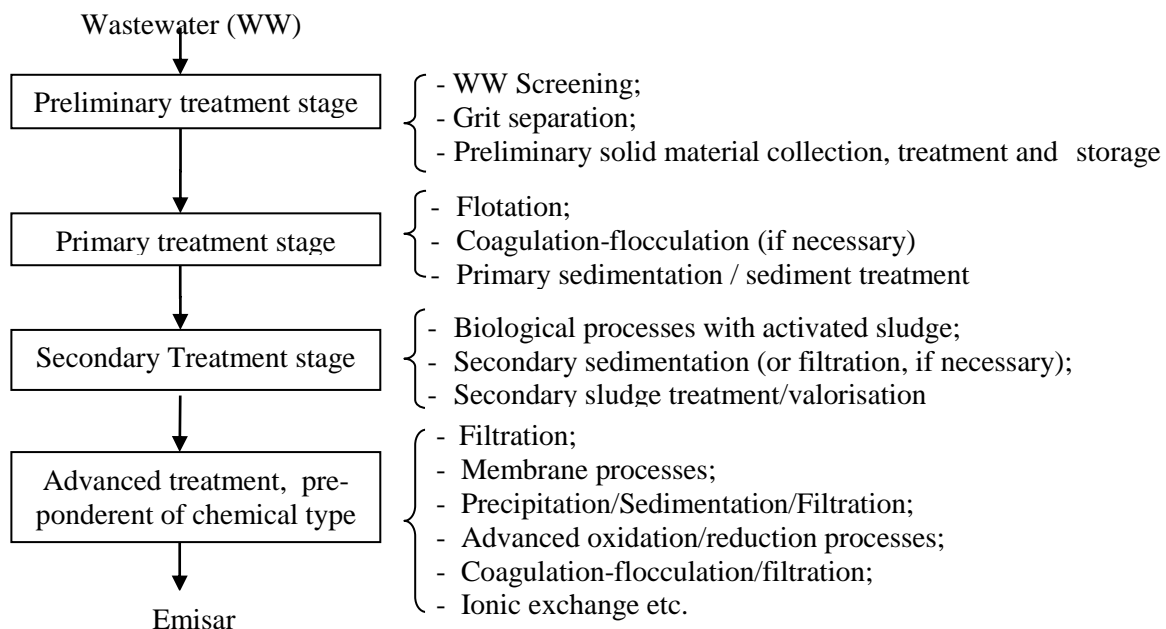


Figure 1. Common stages in technological process of WWs treatment.

One of the most common operations in WW treatment is removal of solids from WW by sedimentation, or sedimentation-like operations. Most WWs contain solids to some degrees (course

and fine materials), and additional solids are created during chemical (precipitation, coagulation-flocculation) and/or biological treatment (in-excess activated sludge). In some instances, the addition of precipitation agents (dissolved chemicals that create solid particles), or coagulant aids and flocculation may be feasible. There are economic constraints (e.g. capital and operating costs) which limit the removal methods of solids to gravity sedimentation and thickening, in most cases, excepting filtration-like operation [3] which is used especially where effluent suspended solids standards are stringent, or in advanced WW treatments, and also centrifugation (a form of sedimentation).

The equipments used for gravity sedimentation and thickening are the sedimentation tanks [6], constructed in any desired configuration such as circular, square and rectangular. Most important features in any configuration are the inlet and outlet structure, and sludge-collection system.

The inflow into the preliminary and primary clarification tank consists of a sludge/water mixture from the grit trap, where the coarse sludge and mineral solids are separated by sedimentation. The restrictive treated WW quality standards impose also additional removal of floating and settling material within the secondary clarification tank. Sludge-collection system controls the width or radial dimension of sedimentation tanks. Usually, standard sizes are chosen rather than ordering specially-constructed equipment such as up to 9 m in width for rectangular sedimentation tank, or up to 20-60 m in diameter for circular tanks. The velocity of WW flowing through the sedimentation tank is usually kept around 0.3 m/min in comparison with velocity through grit channel that is around 18 m/min [5]. At this average velocity, the retention time in a primary sedimentation tank is often around two hours. The settled solids (primary sediment) is scraped to a sump and removed by pumping as primary sludge, being also collected the grease and scum that float to the top of the tank (floatable material). Peak load operation is critical under storm conditions as well when sludge blanket and hydraulic load are increasing, thus exists risk of sludge overflow, situation that must be always avoided.

Engineering responsibility for WW treatment must have in view performing of required WW treatment degree, system design and operation, WW quality standards (both qualitative and quantitative aspects) and also receiving water quality standards for local water resource protection and conservation as safe water resource [2, 6].

The present research work has in view some important objectives such as: (i) investigation of impact caused by operating of individual/single sedimentation-based mechanical stage, associated with different chemical stages (i.e. coagulation and flocculation, chemical precipitation, ionic exchange etc.) on the global performance of WWTP, in the presence of low, medium or high organic content; (ii) evaluation of the lowest and highest level of removal by current WW treatment technologies, or (iii) determination of possibilities to cost-efficient improvements.

2. Primary sedimentation-based mechanical stage applied for WWTP

Primary sedimentation (or primary clarification) is a separation technique of suspended particles and floating material by gravitational settling in a primary WW treatment stage. It is widely utilised for many proposes and usually not used alone. Settled solid material is removed from the bottom as primary sludge, whereas floated material is skimmed from WW surface. If solid particles cannot be separated by simple gravitational means, adequate chemicals (e.g. aluminium sulphate (alum), ferric sulphate or chloride, lime, poly aluminium chloride or sulphate, cationic organic polymers) are added to agglomerate solids into flocs large enough to settle, caused by destabilisation of colloidal and small suspended particles (e.g. clay, silica, iron, heavy metals, dyes, organic solids) and emulsions (oil in WW) entrapping solids (coagulation) and/or agglomeration of these particles to flocs easily settleable (flocculation) [7]. In case of flocculation, it can also use anionic and non-ionic polymers (e.g. anionic and non-ionic polyelectrolytes) [6].

Main characteristics of sedimentation equipments (sedimentation tanks or settlers), some current applications and their limits/restrictions are summarised in table 3 [8], [9]. The treated WW requires regularly control and monitoring of solid content, meaning total suspended solids (TSS), settleable solids or turbidity (T), sedimentation time (t_s) and/or rate (v_s), WW flowing velocity (horizontal - v_o ,

or vertical - v_v), and if chemicals (coagulant/flocculant) are used for settling facilities, the pH needs to be controlled as main operational parameter.

Table 3. Characteristics of settlers used and sedimentation-based applications in WWTPs.

Settler / Sedimentation tanks	
Type	Characteristics
Sedimentation or flat tank	<ul style="list-style-type: none"> - Either rectangular or circular; orizontal flow, max $v_o=0.3-0.6$ m/h; $v_s=0.7-3.0$ m/h; - Equipped with an appropriate scraper of adequate size; - Residence time of about 1.5 to 2.5 (3) h for primary municipal sludges and $\frac{1}{2}$ to $1\frac{1}{2}$ h for secondary sludges; - Orientated toward automatic process control which needs monitoring of effluent solids sludge solids or both with an automatic device
Hopper-bottom tank	<ul style="list-style-type: none"> - Vertical flow, max $v_v=0.042-1.0$ m/h; $v_s=1.1-2.7$ m/h; - Residence time of about 1.5 h for primary municipal sludge; - Not usually equipped with mechanical sludge removal system
Lamina or tube settlers	<ul style="list-style-type: none"> - Plates used to enlarge the sedimentation surface; - Large numbers of small-diameter (2-5 cm) tubes are nestled together; - Overflow rates as high as $290 \text{ m}^3/\text{m}^2 \cdot \text{d}$; - New construction of PVC plastic tube settler in modules of ca 3 m long, 1 m wide and $\frac{2}{3}$ high
Centrifuges	<ul style="list-style-type: none"> - Used for thickening previously concentrated sludge; - Used the same principle as for gravity sedimentation, but an additional force is involved due to radial acceleration, rotating centrifuge basket; - Commercial centrifuge for sludge dewatering is usually of scroll type; - Typical diameters of 0.15 to 0.75 m; rotation speeds of 1,000 to 6,000 r/min
<i>Sedimentation-based applications:</i>	
<ul style="list-style-type: none"> - Collected rainwater clarifying from solids (sand or dust) in sedimentation tank; - Process WW clarifying from inert solids (sand or comparable particles); - Separation of heavy metals or other dissolved species after proceeding precipitation, often with chemical support followed at the end by sedimentation and filtration; - Process WW clarifying from reaction material (emulsified metal compounds, polymers and their monomers) supported by addition of appropriate chemicals; - Removal of activated sludge in primary or secondary clarifier of a biological WWTP 	
<i>Application limits and restrictions:</i>	
<ul style="list-style-type: none"> - <i>Particle size</i>: solid particles must be large enough to be settled, otherwise coagulation and/or flocculation agents will be applied; - <i>Volatile substances in WW</i>: volatile substances must be avoided because of long residence time in the tank, by mixing action when coagulation-flocculation are used for potential release of VOC; - <i>pH</i> (in case of coagulation-flocculation application): it is essential to control the pH range during operation, otherwise it performs poor clarification performance; - <i>Emulsions</i>: stable emulsion cannot be separated and broken by coagulation / flocculation; preceding emulsion breaking is required 	

The amounts of some consumables in preliminary sedimentation-based mechanical stage can vary in range of: 53-93 kg of chemicals (organic coagulant/flocculent)/t of oil/solid, or 0.5-100 g of chemicals/m³ of WW; 0.5-1.5 kW of electric energy (for tank diameter varying in range of 25 to 35 m), and nitrogen for inert atmosphere (for avoiding explosion risk) [8].

As each operation and process involved in WW treatment system, primary sedimentation-based mechanical stage has advantages (i.e. installation simplicity, possibilities of increasing removal efficiency by addition of coagulation and/or flocculation agents, or dissolved air flotation) and also disadvantages (e.g. unsuitable for fine material and stable emulsions, sometimes even with coagulants and flocculants, flocs can embed other contaminants that might cause high toxicity risk and problems in sludge disposing), being used upstream of subsequent treatment steps for protection of downstream facilities [9]. Its removal efficiency must be high enough to achieve this goal, meaning 60% of total suspended solids (TSS), 90-95% of settleable solids, or 80-95% of TSS after coagulation-flocculation; after the final clarifier of central WWTP, TSS value is recommended to be < 10 mg/L. Primary sedimentation reduces also content of organic particles (30-35% of COD_{Cr}) as well TOC/COD_{Cr} ratio, depending of solid TOC in total TOC (TOC - total organic carbon) [8-10]. Sediment sludge and skimmed scum need to be disposed of as waste, if is not suitable to recycle or reuse otherwise; it contains common and/or hazardous compounds (e.g. carbonates, fluorides, metal and/or heavy metal sulphides, hydroxides or oxides, oily scum, even dioxins) which need to be treated accordingly. Moreover, odorous substances from WW impose coverage of sedimentation tank and ducting of the waste gas (using ducts and vents), if necessary, to a treatment system, probably being needed an appropriate safety system (e.g. pressurised nitrogen gas flow system, to avoid explosion risk) [5]. The usual treatment system of separated primary sludge (individual, or in combination with the secondary sludge, after the biological treatment step) consists of a sludge preliminary treatment (i.e. screening, disintegration), chemical conditioning (elutriation with lime, ferric chloride and/or organic polyelectrolyte), mechanical concentration (i.e. gravitational and mechanical concentration with vacuum, press or band filter, dissolved air flotation, centrifuge), stabilisation (i.e. anaerobic, aerobic, alkaline stabilisation, in combination with secondary sludge), dewatering (i.e. natural and/or mechanical dewatering), advanced treatment (drying, incineration, composting) and final safe disposal.

Some costs of sedimentation-based treatment divided in capital and operating costs are indicated to be: (i) *capital costs*, ca 1.2-4.8 million Euro (according to BREF4) for sedimentation tank of 100 m³/h capacity, and 4 million Euro (adapted from BREF4) for laminar or tube settler of 25 m³/h capacity, and (ii) *operating costs*, ca 20-100 Eur (BREF4) per m³ (settler of 25 m³/h capacity) [8].

3. Experimental part

3.1. Characteristics for the studied urban and industrial WWs management system

The studied WWs are real effluents, treated or not in central (urban) and/or decentralized (industrial) WWTP (mechanical/chemical/biological treatment steps), with varying composition dependent of origin, raw materials, production technology, treatment facilities and dilution rates.

The management system of each studied WW (i.e. *urban WW*, from cities with ca 18,000 inhabitants from NE and SE region of Romania, Falticeni (2009) and Tecuci (2013) towns), or *industrial WW*, produced in a Romanian white sugar manufacturing company (from sugar cane) (2014), or basic aromatic organic chemicals synthesis company (2009) considers three basic systemic components as: (i) WW collection, (ii) WW treatment and (iii) treated WW disposal or reuse.

The first component, *WW collection*, is at least important for WW treatment and disposal, but costs more than 60% of total WW management system budget in centralised systems, particularly in small communities with low population densities, associated with industrial platform site [11-13], being kept as minimal as possible in decentralised systems [2].

For the second component, *WW treatment*, WWTP continues to represent one of the major investments due to high capital cost in addition to operation and maintenance costs [2]. The

decentralised WW system are simpler and cost effective referring to centralised WW system which needs large capital investment for sewer system and pumping costs, > 70% of total annual budget [14-16].

In general, centralised systems collect and treat large WW volumes for entire large communities, associated with industrial platform site (using large pipes, pumping systems, various access routes, constructions, equipments and treatment technologies, far away from the generation points) related to decentralised systems which individually collect, treat and dispose/on-site reuse the treated WW at, or near the generation point [11], [12], [17], [18].

The third component, *treated WW disposal*, is based on: (i) *usual disposal methods* by simple evaporation, discharge in surface water, or subsurface soil absorption/adsorption systems, and (ii) *reuse methods* by passing through trenches and beds, stored in special receiving basins, and used for proper domestic, irrigation, or industrial facilities [2, 12].

The studied industrial WWs are produced in Romanian private companies, being treated in centralised (on-site Carom platform, Onesti), or decentralised (on-site company emplacement, Roman) WW treatment facilities (at source) and discharged into emisar – local permanent watercourse (Trotus, or Moldova rivers). All process waters for the studied industrial companies are ensuring from nearby local watercourse and ground waters from some individual drillings [19] with additional water treatment (based on demineralization, chemical precipitation, ion exchange to attain required quality of process water, or from recycling/on-site reuse of specific type of treated WW).

The studied urban WWs (i.e. max average WW flow of 0.27 or 0.31 m³/s, deserving Falticeni or Tecuci town, with ca 18,000 inhabitants, or more) are collected from different sources (domestic, industrial, market/commercial units) in the urban sewer system and mixed (to obtain municipal or urban WW), being treated in central WWTP (mechanical-biological type) and discharged into emisar – local permanent watercourse (i.e. Targului, or Barlad river).

All characteristic quality indicators of studied WWs (i.e. suspended solids, turbidity, fixed residues, pH, organics expressed as COD_{Cr} or BOD₅, ammonia, nitrates, nitrites, total phosphorus and nitrogen, chlorides, residual chlorine, phenols, extractible substances, detergents, cyanides, metals, etc.) have been analysed using internationally approved standards and reference materials based on spectrophotometer methods, pH meter or other advanced apparatuses (data available from owners).

The environmental risk of toxic residuals in treated WW (WWTP effluent/discharge) is frequently and easily expressed by *risk quotient (RQ)*, i.e. $RQ = MC_{eff}/PNEC$, where: MC_{eff} is the maximal concentration of toxic residuals in treated WW (effluent) or river water and $PNEC$ is 'predicted no effect concentration'. The estimated risk levels can vary in range of: *low risk* ($RQ = 0.01-0.1$), *medium risk* ($RQ = 0.1-1$) and *high risk* ($RQ > 1$) [19].

3.2. Primary sedimentation-based mechanical step: characteristics and its connection with other physical-chemical or biological treatment steps

The studied central WWTPs are using conventional mechanical (screening/homogenization/air flotation/primary sedimentation), chemical (coagulation-flocculation, neutralization) and/or biological (bio-oxidation by activated sludge, with predominant mechanical (80%), or pneumatic (20%) aeration systems, followed by secondary sedimentation) treatment steps for reduction of solid materials, organic load, and separation of sludge-based flocs which sometimes requires an advanced (tertiary) treatment step for reduction of total nitrogen and phosphorus content (table 2). For the studied industrial WWs, there are operating central or decentralised WWTPs with mechanical-chemical-biological treatment steps associated, if necessary, with an advanced treatment stage (e.g. oxidation and stabilisation ponds, lagoons). Both WW treatment degree and cost are engineering concerns of plant operators, being needed to provide maximum WW treatment at minimal cost [5], [6].

Primary sedimentation-based mechanical units existing and functioning in the studied WWTPs are one of significant equipments acting for reduction of solid loads and organic (solid and dissolved) content, facilitating the normal functioning of further treatment stages. The studied primary settlers (i.e. sedimentation tanks) are characterized mainly through shape (rectangular or radial) or

dimensions, flowing direction (horizontal, or vertical) and velocity (v_o , or v_v), sedimentation rate (v_s , influenced by each separating solid particle sedimentation velocity and solid size distribution), residence time (t_s), designed performance of primary sedimentation and further impact onto the total WWTP performance (%).

Separation characteristics of different WW solid particles into sedimentation-based mechanical WW treatment stage (primary settlers) are presented in table 4 [9].

Table 4. Horizontal (v_o) and sedimentation (v_s) velocities referring to diameter of different settleable solids.

Solid particle diameter, [mm]	Horizontal flowing velocity – v_o [m/s]			Sedimentation velocity – v_s [m/s]		
	Sand ^a	Coal ^b	Municipal WW settleable solids ^c	Sand ^a	Coal ^b	Municipal WW settleable solids ^c
1.0	0.410	0.230	0.180	0.140	0.042	0.034
0.5	0.300	0.160	0.130	0.072	0.021	0.017
0.2	0.190	0.100	0.080	0.023	0.007	0.005
0.1	0.130	0.070	0.055	0.007	0.002	0.0008
0.05	0.090	0.050	0.040	0.0017	0.0004	0.0002
0.01	0.041	0.023	0.018	0.00008	0.00002	0.000008
0.005	0.030	0.016	0.013	0.00002	0.0000004	0.000002

^a sand particles with density of $d=2.65 \text{ g/cm}^3$; ^b coal particles with density of $d=1.60 \text{ g/cm}^3$;

^c municipal WW settleable solid particles with density of $d=1.20 \text{ g/cm}^3$.

4. Results and discussion

For the studied WWs management systems, few significant structural and compositional characteristics are presented in table 5, consisting of information about each component of developed WW management system, together with concrete data about treatment facilities, and its designed performance, i.e. WW and primary sludge pumping system, existing gritting traps, settlers, associated or not with coagulation-flocculation installation, or other treatment facilities [20-25].

4.1. Primary sedimentation contribution to reduction of WW polluting loads

The industrial WWs produced from specific industrial processing activities (i.e. basic aromatic organic chemicals synthesis for aromatic alimentary food industry and flavours) can be toxic to many forms of living organisms (i.e. it contains acids, bases, other hazardous species that charge usually the environment rather than directly attack organisms, such as different poisons as cyanides, toxic compounds as heavy metals, phenol and its derivatives, and high-temperature cooling waters that can alter the aquatic environment or cause thermal shock) [5], therefore must be obligatorily treated.

In many cities, it was found that WW treatment degree necessary to protect receiving water quality has increased much faster than population. In addition, the WW treatment cost is roughly exponentially referring to the extent of treatment stages which include obligatorily primary sedimentation-based mechanical steps. A lower number of treatment stages in a WWTP management system is always wanted from cost-effective criteria, but usually a minimal number of other conventional or advanced treatment stages are implemented to satisfy the exigent and restrictive water resource/treated WW quality and safe standards. The principal non-treated WWs characteristics (WWTP input/inlet) and treated WWs by mechanical treatment stage (i.e. effluent from primary sedimentation, without coagulation-flocculation in the case of urban WWTP and with additional coagulation-flocculation or stabilisation step in the case of industrial WWTP) or mechanical-

biological treatment steps (final effluent from urban WWTP) are presented in Table 6, considering especially some common quality indicators required to be controlled in each compliance plan for comparison with the maximal permitted limits (recommended by environmental controller).

Table 5. Characteristics of studied urban or industrial WW management systems.

WW origin / WW generation source	WW management system characteristics
<p><i>Industrial /</i></p> <p>Vegetal food processing / Canning industry</p> <p>(i.e. private Company – Agrania Romania SA Roman Branch (NE Romania, 190 employees, total surface of 113.058 ha; 100-120 days/year of normal functioning, and 24 h/day, 7 days/ week; processing sugar cane till raw white sugar, ca 15-17% production efficiency) [21] (with WWTP No. 1)</p>	<p>- <i>WW Type/flow</i>: decentralised (decentralised WWTP, mechanical-chemical-biological-advanced treatment stages), water consumption of 29.78 m³ water/ t of white sugar; average WW flow of 5600 m³/day, or 0.069 m³/s; designed efficiency of 95-98% for TSS and BOD₅;</p> <p>- <i>WW collection</i>: separative collecting system from: (1) hydraulic transport and washing step of raw vegetal materials (pipes, pumping station-1.5 kW, regular pipe of treated WWs evacuation in Cordun pond); (2) WW neutralisation installation, and (3) mechanical-biological treatment (functioning from 2014) (pipes of 1.2 m diameter);</p> <p>- <i>WW Treatment</i>: decentralized WWTP (named WWTP No. 1) composed of: (1) pre-treatment system of WWs from hydraulic transport and washing step of raw vegetal materials (2 basins for heavy solids separation, 2 radial settlers and 2 homogenizers); (2) WW neutralisation installation of 250-400 m³ (pH=6.5-8.3) (2 buffer reservoirs, 3 pumping units for aggressive WWs, 2 neutralisation units of 250 m³ (80 m³/h, 3-4 h), 3 recirculation and evacuation pumps of washing waters, 1 pumping unit for 2% lime milk); (3) mechanical-biological treatment plant (2 rectangular settlers (concrete), 1 longitudinal settler (soil), biological Nolte lagoon, mixed Nolte-Gould aerobic-anaerobic biological treatment, COD_{Cr}/N/P = 200/5/1, 4 WW collecting basins (100 m³), 1 aeration/oxidation basin (4,000 m³), 1 secondary settler of 34 m in diameter (2,815 m³); for sludge line - sludge evacuation (pumping and recycling) and in-excess sludge treatment (natural dewatering);</p> <p>- <i>WW disposal</i>: direct discharge in emisar (Moldova river) through regular pipe of 0.5 m in diameter.</p>
<p><i>Industrial /</i></p> <p>Basic aromatic organic products synthesis</p> <p>(i.e. private company – Aroma Rise SA Onesti (NE Romania, 50 employees, total surface of 1.84 ha; continuous annual functioning, synthesis</p>	<p>- <i>WW Type/flow</i>: on-site (Carom platform) centralised system (central WWTP, mechanical- chemical-biological), average WW flow of 189.04 (industrial) and 0.60-1.125 (domestic) m³/h;</p> <p>- <i>WW collection</i>: separative collecting system: (i) industrial WWs (Old Carom sewer system, 4 km length, underground Premo pipes of 0.8 m in diameter); (ii) domestic WWs, and (iii) rainwater (underground Premo pipes of 1.2 m in diameter, pumping station), regular pipe of treated WWs evacuation in emisar (Premo pipes, L=0.82 km);</p> <p>- <i>WW Treatment</i>: central WWTP (Carom platform; named WWTP No. 2), composed of: (1) mechanical-chemical stage for max WW flow of 0.376 m³/s (pumping station, gritting, homogenisation/coagulation-flocculation/neutralisation basin, primary settler - retention time of 4-5 days), and (2) biological stage for max WW flow of 0.389 m³/s (1</p>

of basic aromatic products for alimentary industry, food, flavours as C14-C16 aldehydes, γ and ω lactones, cyclic cetones, esters, glycolates, ntermediate fractions from petroleum products) [20, 22], [23]	aeration/oxidation basin, 2 secondary radial settlers of 35 m in diameter, chemicals used as nutrients (10% industrial lime for pH correction, 10% tri-sodium phosphate, 10% urea); it exists also 1 biofilter (h=4 m, chemically inert granite support, 4-8 cm-material size); for sludge line - (3) sludge evacuation (pumping, recycling) and in-excess sludge treatment (mechanical and gravitational concentration to 6-10% solids, and dewatering);
(with WWTP No. 2)	- <i>WW disposal</i> : direct discharge in emisar (Trotus river) through regular pipe of 1.0 m in diameter, L=0.5 km, or recycling to supplying pipe with industrial process water
Urban / WW and water service (i.e. Termsal SA Co. (SE Romania, Tecuci-Galati, ca 18,956 inhabitants deserved); max daily discharging volume of 35,160 m ³) [24]	- <i>WW Type/flow</i> : Centralised (central WWTP, mechanical-biological treatment stages), average flow of 0.371 m ³ /s; designed global efficiency of 90-95% for TSS and BOD ₅ ; - <i>WW collection</i> : separative collecting system (Premo pipes of 0.2 and 1 m indiameter, 2 pumping stations with Grunfos electropumps of 1.5 kW, regular pipe of treated WWs discharging in emisar), ca 81.1-90 km total length, deserving ca 45-55% from total inhabitants, with local non-treated WW discharges in emisar; - <i>WW Treatment</i> : central WWTP (named WWTP No. 3), composed of: for WW line - (1) mechanical stage for WW flow of 0.365 m ³ /s (pumping station, gritting, greases separation, primary sedimentation), and (2) biological stage for WW flow of 0.19 m ³ /s (aeration basin of 1,800 m ³ , 4 aeration turbines of 0.188 m diameter and motor of 22 kW, 2 secondary radial settlers of 35 m in diameter; for sludge line - (3) sludge evacuation (Grundfos 4 kW or 22 kW pumping and recycling) and in-excess sludge treatment (natural dewatering, 19 compartments of 50 m (length) x 30 m);
(with WWTP No. 3)	- <i>WW disposal</i> : direct discharge in emisar (Barlad river) through evacuation pipe of 1 m in diameter, vaccum pump of 1.5 kW
Urban / WW and water service (i.e. Municipality service (NE Romania, Falticeni-Suceava, ca 17,496 inhabitants; max daily discharging volume of 25,056 m ³) [25]	- <i>WW Type/flow</i> : Centralised (central WWTP, mechanical-biologica treatment stages); average flow of 0.21 m ³ /s; designed globa efficiency of 96% for TSS and BOD ₅ ; - <i>WW collection</i> : separative collecting system (pipes of 0.6 m in diameter, 4 pumping stations with Brates 250b electropumps of 30 kW/1,500 rpm, regular pipe of treated WWs in emisar), deserving ca 50-55% from total inhabitants, with non-treated WW direct discharges in emisar; - <i>WW Treatment</i> : central WWTP (named WWTP No. 4), composed of: for WW line - (1) mechanical stage for WW flow of 0.29 m ³ /s (pumping station, gritting, greases separation, primary sedimentation), and (2) biological stage for WW flow of 0.16 m ³ /s (3 aeration basins of 5,040 m ³ , l=37 m, h=4.5 m; 3 aeration turbines Gardner-Denver 140 L and motors of 55 or 75 kW/2953 rpm, 2 secondary radial settlers of 35 m in diameter and 3 m in heighth; for
(with WWTP No. 4)	

sludge line - (3) sludge evacuation (Cris 150b pumping and recycling, 11 kW motor) and in-excess sludge treatment (natural dewatering, total surface of 1 ha (10 compartments, specific load of 0.729 t/m².year);

- WW disposal: direct discharge in emisar (Targului river) through evacuation pipe of 1 m in diameter, vaccum pump of 1.5 kW

Table 6. Maximal and minimal values (mg/l) of some common physical-chemical quality indicators for non-treated WW (*inlet-IN*), after primary sedimentation stage (*1Sed*), and final treated WW (*outlet-OUT*).

Quality indicators, [mg/l]	WWTP No. 1 (2014)			WWTP No. 2 ^a (2009)			WWTP No. 3 (2013)			WWTP No. 4 (2009)			M.A.C. *, [mg/l]	
	IN	1Sed	OUT	IN	1Sed	OUT	IN	1Sed	OUT	IN	Sed	OUT		
Suspended solids	831	578	26	124	58	26	404	142	37	216	96	29	35	
Fixed residues	2766	1864	257	1400	1350	790	1680	1498	1000	1460	1240	998	2000	
pH	6.8	6.9	7.3	6.7	6.8	7.4	7.6	7.3	7.2	7.7	7.5	7.4	6.5/8.5	
COD _{Cr} , [mg O ₂ /l]	2467	1689	86	570	382	147	614	388	130	132	91	30	125	
BOD ₅ , [mg O ₂ /l]	2329	1514	15	114	84.2	14.8	107	72.4	18.5	97	63.2	16.5	25	
NH ₄ ⁺ [mg N-NH ₄ /l]	30.3	-	0.3	3.1	-	1.4	17.8	16.2	12.4	16.5	15.4	13.2	3.2	
NO ₃ ⁻ [mg N NO ₃ ⁻ /l]	6.5	-	1.4	4.6	-	2.5	7.8	7.4	5.5	6.3	6.1	4.3	5.6	
NO ₂ ⁻ [mg N-NO ₂ ⁻]	0.2	-	0.05	0.12	-	0.27	1.49	1.12	0.60	1.12	1.08	0.40	0.3	
P total	0.8	0.7	0.3	0.02	0.02	0.02	8.92	6.12	0.62	6.42	5.92	0.50	0.2	
N total	47.8	42.4	5	9.9	9.1	3.5	29.8	24.8	18.2	25.4	23	17	10	
Chlorides (Cl ⁻)	98	86	47	450	324	249	56	38	24	58	52	36	500	
Residual chlorine	-	-	-	-	-	-	0.4	0.38	0.20	0.36	0.36	0.2	0.2	
S ²⁻ + H ₂ S, [mg S/l]	0.86	0.80	0.4	1.94	1.82	1.56	1.52	1.11	0.38	1.24	0.78	0.32	0.5	
Extractible subst.	18	10	3.5	160.5	35.2	14.5	21.2	2.8	1.6	18	6.2	5	20	
Detergents	0.65	0.46	0.2	0.21	0.19	0.19	0.11	0.96	0.08	18	6.6	0.65	0.5	
Phenols	0.15	0.10	10 ⁻³	6.4	6.15	0.11	2.4	2.2	0.3	1.6	1.4	0.2	0.001	

Cyanides (CN ⁻)	0	0	0	0.12	0.15	0.1	0.15	0.11	0.1	0	0	0	0.1
Cooper (Cu ²⁺)	0.14	0.10	0.1	1.3	1.12	0.03	0.2	0.18	0.09	0.22	0.20	0.08	0.1
Total iron ions	4.88	3.82	0.94	4.66	3.22	2.36	5.65	2.44	1.0	5.26	2.56	0.98	5

Notes: (1) Permitted limits for other toxic organics in case of investigated basic aromatic organic synthesis industry are: toluene=14.6 ug/l (M.A.C.= 0.006 ug/l); polyaromatics (PAHs) = 14.6 ug/l, trichlorobenzene (TCBs)= 0.0012 ug/l, etc.;

(2) M.A.C. – maximum admissible concentration, corresponding to permitted limits from available legislative norms (NTPA 001) for discharging the treated WWs in natural receptor (emisar) (Romanian Government Ordinance No. 352/2005 [26].

From table 6, it can conclude that the mean measured values of all quality indicators were not exceeding the permitted legislative limits in WWTP No. 1 (sugar cane processing company), but, for all other WWTPs, the permitted limits are a little bit exceeded in case of few studied quality indicators such as: (i) COD_{Cr}, S²⁻ and H₂S, phenols, in WWTP No. 2 (basic aromatic compounds synthesis); (ii) suspended solids, ammonia, nitrites, total phosphorus and nitrogen, detergents, phenols in WWTP No. 3 (urban WWTP of Tecuci town), or (iii) nitrites, total nitrogen and phosphorus, detergents and phenols in WWTP No. 4 (urban WWTP of Falticeni town).

A required standard quality must be related to the treated wastewater when it is used as processing water, or for recycling/reusing goal, and also if is discharged in local receiving watercourse [1, 5]. The specific site standards, or permitted maximal limits are considering: (i) requirements of permit conditions (compliance with permit requirements), i.e. ensuring continuous compliance with maximum permissible discharge (emission) limit values; (ii) specific limitations on the ecotoxic content of any final outfall in accordance with the limits set for receiving aquatic receptor (reduction of eco-toxic effects), e.g. the achievable values for final discharge to a water body such as T_F=2 (fish test), T_D=4 (daphnia test), T_A=8 (algae test), T_L=16 (luminescent bacteria test), and T_M=1.5 (mutagenity), and aims to further reduce of toxic impact of WW discharge considering acute toxicity (to fish, daphnia and bacteria), chronic toxicity to algae, and mutagenicity, and (iii) requirements of continuous reduction of polluting loads [7, 8].

Data from table 7 indicate that in the final WWTP effluent (*eff_{out}*), all residuals have *medium risk*, excepting *no risk* for total phosphorus in WWTP No. 2, and *high risk* for total phosphorus (possibilities of polluting eutrophication episodes) in WWTP No. 1,3,4, detergents in WWTP No. 4, and phenols in WWTPs No. 2,3,4.

The mixing of WWTP discharge in river water is not conservative for suspended and bottom deposited solids (especially organic solids, or biosolids) and other toxic, or in-excess discharged residuals as heavy metals, extractible substances, detergents, different phosphorus and nitrogen species, other organics etc., being sorbed by solid particles of receiving water, precipitated and agglomerated, decomposed by solar light, oxidising/reducing species existing or formed in river water, and/or complexated by existing ligands.

The environmental risk of toxic residuals present in treated WWs (effluent from primary sedimentation step (*eff_{1Sed}*), or secondary sedimentation after biological treatment step (*eff_{out}*)) and receiving river (1 km-downstream of discharging/control point) is commonly expressed by risk quotient (*RQ*) and estimated qualitatively in terms of *no risk*, *low*, *medium* or *high risk* [19]. For data shown in table 6, the environmental risk of toxic residuals (i.e. extractible substances, total phosphorus, detergents, phenols, cooper ions and cyanides) varied as (table 7):

Table 7. Maximal concentrations of toxic residuals in treated effluents (MC_{eff}), predicted no effect concentration ($PNEC$), risk quotient (RQ) and its estimated risk levels.

Quality indicator	WWTP No.	$MC_{eff-1Sed}$	$MC_{eff-OUT}$	$PNEC$	$RQ_{eff-1Sed}$	$RQ_{eff-OUT}$	Risk level (eff-1Sed)	Risk level (eff-OUT)	Risk level (river)
Extractible substances	1	10	3.5	20	0.5	0.175	medium	medium	low
	2	35.2	14.5		1.76	0.725	high	medium	medium
	3	2.8	1.6		0.14	0.08	medium	low	low
	4	6.2	5.0		0.31	0.25	medium	medium	low
Total phosphorus	1	0.66	0.30	0.2	3.3	1.5	high	high	medium
	2	0.018	0.015		0.09	0.075	low	low	no
	3	6.12	0.62		30.6	3.1	high	high	medium
	4	5.92	0.50		29.6	2.5	high	high	medium
Detergents	1	0.46	0.2	0.5	0.92	0.4	medium	medium	low
	2	0.19	0.19		0.38	0.38	medium	medium	low
	3	0.96	0.083		1.92	0.166	high	medium	medium
	4	6.60	0.65		13.2	1.3	high	high	medium
Phenols	1	0.10	0.001	0.001	100	1	high	medium	medium
	2	6.15	0.11		6150	110	high	high	high
	3	2.20	0.3		2200	300	high	high	high
	4	1.40	0.2		1400	200	high	high	high
Cooper ions (Cu^{2+})	1	0.10	0.06	0.1	1	0.6	medium	medium	low
	2	1.12	0.03		11.2	0.3	high	medium	no
	3	1.18	0.09		11.8	0.9	high	medium	low
	4	0.20	0.08		2	0.8	high	medium	low
Cyanides (CN^-)	1	0	0	0.1	0	0	no	no	no
	2	0.15	0.1		1.5	1	high	medium	low
	3	0.11	0.1		1.1	1	high	medium	low
	4	0	0		0	0	no	no	no

- in case of effluent- eff_{1Sed} after primary sedimentation stage from *no risk* (for cyanides, in WWTP No. 1 and 4) to *high risk* (for extractible substances in WWTP No.2; total phosphorus in WWTPs No. 1,3 and 4; detergents in WWTPs No. 3,4; phenols in all WWTPs; copper in WWTPs No.2,3,4 and cyanides in WWTP No. 2,3) (table 7);
- other residuals posed *medium risk*, excepting total phosphorus in WWTP No.2 which manifested *low risk* (Table 7).

Specific preventive measures must be adopted in order to reduce the eco-toxic risk of final WWTP effluent directly discharged in emisar, or recycling/reuse on-site company emplacement.

Moreover, the similarity of WWTP outflows does not prove that WWTP effluents contribute specifically (aggressive or highly toxic) to reactive solids fluxes in river water, but indicates that further studies should be devoted to influence of WWTP upon bioavailability of polluting solids (suspended materials), trace metals and/or hazardous species to organisms in river water.

4.2. Performance of primary sedimentation step and total WW treatment in removal of solids and organic content

For the studied WWTPs, the performance in removal of solids and organic content is presented in table 8, considering the solid particle origin and size, concentration (inlet), or sedimentation velocity (v_s), and also table 9, with the real treatment efficiencies of existing primary sedimentation stages related to the total WWTP performance, especially in suspended solids and organic content removal, but not only.

Table 8. Removal of suspended solids (%) in primary sedimentation vs. initial solids content (mg/l) and sedimentation velocity (v_s).

Removal of suspended solids, [%]	v_s , [m/h] (or superficial load, [$\text{m}^3/\text{m}^2 \cdot \text{h}$])		
	$C_{ss}^* \leq 200$ [mg/l]	$200 \leq C_{ss}^* \leq 300$ [mg/l]	$C_{ss}^* > 300$ [mg/l]
30 – 45	2.3	2.7	3.0
45 – 50	1.8	2.3	2.6
50 – 55	1.2	1.5	1.9
55 – 60	0.7	1.1	1.5

* C_{ss} – concentration of suspended solids in WWs

It seems that contribution of primary sedimentation-based mechanical stage at total WWTP performance for removal of suspended solids and organic content (expressed by COD_{Cr} or BOD_5) is important, being estimated as 30.445 % suspended solids, 30.699 % COD_{Cr} , or 34.531 % BOD_5 (without additional coagulation-flocculation step) till 53.226-64.85% suspended solids, 30.699-36.816% COD_{Cr} , or 26.24-34.845 % BOD_5 (with additional coagulation-flocculation step) (table 9).

Table 9. Removals of solids and organic content after primary sedimentation (*ISed*) and in final discharging effluent in emisar (*OUTlet*).

Quality Indicator	Removal, or WW treatment degree, [%]								Minimal/ Maximal efficiency, [%]	
	WWTP No. 1		WWTP No. 2		WWTP No. 3		WWTP No. 4			
	1Sed	OUT	1Sed	OUT	1Sed	OUT	1Sed	OUT	1Sed	OUT
Suspended solids	30.445	96.871	53,226	79.032	64.851	90.842	55.556	86.574	30.445/ 64.85	79.032/ 96.871
Fixed residues	32.610	90.709	3,571	43.571	10.833	40.476	15.068	31.644	3,571/ 32.610	31.644/ 90.709
COD _{Cr} . [mg O ₂ /l]	31.531	96.105	32,930	74.211	36.816	78.841	30.699	77.508	30.699/ 36.816	74.211/ 96.105
BOD ₅ . [mg O ₂ /l]	34.976	98.935	26,140	87.018	32.336	82.710	34.845	82.990	26,140/ 34.976	82.710/ 98.935
P total	17.50	62.50	10,000	25.00	31.390	93.049	7.788	92.212	7.788/ 31.390	25.00/ 93.049
N total	11.213	89.540	7,411	64.975	16.800	38.833	9.677	33.596	7,411/ 16.800	33.596/ 89.540
Extractible substances	44.444	80.556	78,069	90.966	82.69	92.453	65.556	72.222	44.444/ 91.509	72.222/ 92.453
Detergents	29.231	69.231	9,524	9.524	11.111	23.148	63.333	96.389	9,524/ 63.333	9.524/ 96.389

The secondary sedimentation after the biological treatment increases percentage of suspended solids removal in all WWTPs to 79.032-96.871 % (more than 1.42-2.57 times) and also organic removals to 74.211-96.105 % COD_{Cr} (more than 2.42-2.61 times) and 82.71-98.935 % BOD_5 (more than 2.37-3.152 times), being influenced significantly by biological treatment efficiency, nutrients addition, and maintenance of normal operational conditions in the biological treatment equipment.

For all analysed physical-chemical quality indicators, there are performed removals in WWTPs (table 9) that contribute to significant reduction of polluting organic and mineral load, but some of residuals are exceeding a little bit the maximum permitted limits, therefore technical and management improvements, or technological process optimisation must be implemented and process-integrated measures adopted, when possible.

Concludingly, the studied WWs treatments were very efficient in decreasing the amount of suspended solids and fixed residues (dissolved salts) in treated WW effluent, with more than 30-53% after primary stage and 79-96 % after total WW treatment (outlet of secondary, or advanced stage).

4.3. Cost-effective improvement of WW treatment management

Reduction of polluting discharge via final WW is part of the scope of vertical BREFs, being items of good management practice, and also taken into consideration when implementing a WW management system on a site. Process improvements in both new and existing WWTPs for advanced environmental protection are frequently required process-integrated, or production-integrated measures which are intended to reduce, or even avoid the production of residuals directly at source before they become a discharge [3]. These improvements help to decrease costs for additional treatment measures as well as increase economic efficiency by increasing production yield treatment and/or decreasing input of raw material and chemicals, but can also influence the disposal costs and restrictions/limitations of end-of-pipe treatments [9]. Although the WW production prevention and implementation of process-integrated measures are becoming increasingly significant, WW treatment techniques will remain essential contributors to the control of emissions into the aquatic environment, mainly when process-integrated measures are not feasible for existing production.

Some recommended techniques to be used for the prevention, reduction and recycling of residuals and also advanced environmental protection are consisting of: (i) optimisation of process steps; (ii) improved plant technology, process control and reaction sequence; (iii) technical adaptations to the process; (iv) recycling of auxiliaries (e.g., washing water); (v) recycling of residues immediately during the process; (vi) use of residues as raw material for other productions and/or for energy generation, etc.

The studied complex industrial production sites have normally an extensive system for the collection and treatment of process water, commonly jointed with an operational advanced WWTP with an on-site biological treatment stage. Combined treatment of WW streams from different origins (e.g. domestic and/or industrial WWs) may induce the risk of persistent contaminants escaping at control, and sometimes even detection, because of dilution, or adsorption onto the activated sludge, fact that counteracts to the obligation to prevent or control these substances at source, or leads to a too contaminated sludge for further use or treatment (e.g., anaerobic digestion, composite products manufacturing, soil amendment agent, etc.) [7].

Reduction of polluting loads in the studied WWs involves implementation of some cost-effective actions and recognition of its significant contributions to emission reduction targets [8] such as:

- Introduction of a pricing system (e.g. an internal 'Polluter Pays Principle' (PPP) for discharge from individual production units which are internally charged with the costs of treatment facilities according to their share of pollutant input, or internal awards (bonus payment) for operational improvement proposal, or internal competition for reducing process disturbances and accidents);
- Introduction of objectives for release prevention in design of new or modified facilities and processes (e.g. recycling of starting compounds or products, or water conservation measures);
- Preventive maintenance and appropriate control technology to minimise emissions and losses;
- Implementation of engineering and operating controls and procedures, with criteria for improvement of prevention, early detection of releases, etc. associated with investigation to identify corrective actions to prevent recurrence;
- Communication with employees and public regarding information on emissions, progress in implementation of reduction and future plans.

For all studied WWTPs, the environmental manager was adopted a strategic modernisation and reparation plan for its proper sewer system, WW treatment system, treated WW disposal or even reuse/recycling of treated effluents, and also sludge treatment optimisation and its final valorisation.

5. Conclusions

All mechanical WW treatment stages decrease significantly the suspended solids content of both mineral and organic origin, due to efficient solid particles separation as primary or secondary sludge, or sorption onto suspended solids, or other additional reactions. Some characteristics of primary sedimentation-based treatment steps, including its advantages and disadvantages and estimated performance were shortly discussed.

Four case studies of urban and industrial WWTPs were evaluated in terms of total removal yield, found not less than 53.226-64.85 % in primary stage, and 79.032-96.871 % after secondary stage for total suspended solids. The total removal yield was lower for fixed residues (salts), dissolved organics and nutrients. Thus, some toxic residuals were found in treated WWs (WWTP effluents), and their risks estimated by risk quotient (*RQ*), which vary specifically in each WWTP from *no risk* to *high risk*.

Primary sedimentation was found to be effective treatment stage for solid matters removal in all WWTPs, but some improvements are still individually needed for avoiding toxic residuals in treated WWs, including implementation of additional advanced stage, especially for removal of residual total nitrogen and phosphorus content in the urban WWTP, and integrated preventive measures.

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