Autonomous integrated system for domestic wastewater treatment by reusing water and sludge

[1]Mircea Craciun, [1]Daniela Ignat, [1]Vlad Grigore, [1]Suciu Liviu,
[1]Corina Berkesy, [2]Valer Turcin, [3]Bartha Sandor

[1] S.C. ICPE Bistrita S.A., Bistriţa, Romania; [2] ICPE – Centre 5 Bucharest, Romania;
[3] ICPE – Centre 6 Bucharest, Romania. Corresponding autor: M. Craciun,
craciunmircea@icpebn.ro

Abstract. This paper deals with the creation of an energetically independent, profit-making integrated wastewater treatment system, by water and sludge reutilisation, with low operation costs. The integrated system will include a mechanical-biological wastewater treatment plant with active sludge and biological ponds, a green energy catching and storing station and a greenhouse. The wastewater treatment plant will combine the biological treatment technology with active sludge and the wastewater treatment with the biological ponds, which will be used as buffer-tanks for irrigation, as well. The green energy producing and storing plant will be composed by photovoltaic solar panels and will supply the wastewater treatment plant and the greenhouse with electrical power. The greenhouses for water and sludge reutilisation will use 20 to 100% treated water and 100% sludge and will support water-loving flowers, ornamental plants and technical plants. They will be endowed with a high performance irrigation system and heating installation for winter. An approximate 50-150% benefit from the operation expenses is expected (after covering the treatment and cultivation expenses). The integrated system will be controlled and monitored by a continuous automation and control installation in real time, which will send the parameters of the wastewater treatment, irrigation and ventilation process to the operator's room.

Key Words: wastewater treatment, reutilisation, integration, green energy.

Introduction. Water is vital for supporting life and for the development of the biological habitats. It is also the fundament of a long-lasting and efficient sanitation. Out of nearly 7 billion human beings living on our planet, almost half of them have access to water by network connections. However nearly 1 billion people do not have access to the drinkable water of the system, thus resorting to unprotected wells and springs, canals, lakes or rivers for getting the necessary water (The Council's Directive 86/278/CEE; Government's Decision 750/2008).

The World Health Organisation set up the minimal amount to approx. 20 litres of water per person and day, this amount being very small from the point of view of the health, as the optimal amount for providing public health and hygiene would be 100 litres per person and day. Apart from the water needed for people and plants, the animals and the other organisms also need a minimal amount of water. The necessary water can be supplied if the existing water is efficiently managed and reused where possible (Rose 1999). Being more severe with the water treatment procedures, we must find several means for recycling it in order to fully retrieve all nutrients, from feces, urine and greywater, to the benefit of agriculture, while minimising water pollution. Water should also be used economically and reused at its fullest possible capacity, notably for sustainable irrigation purposes (http://aggie-horticulture.tamu.edu/ faculty/hall/ellisonchair/ water/ b1278 .pdf).

For doing so, we aim at designing and implementing an integrated treatment system for small isolated communities that have a low flow rate emissary or no emissary at all and where the water deficit does not allow irrigation, a system that could reuse water and sludge and provide low operation costs, energetic independence and profitability for the beneficiary.

Composition of the integrated wastewater treatment system. The integrated system will be composed of: a mechanical-biological treatment plant with active sludge and biological ponds, a green energy capturing and storing station and a greenhouse. In the Figure 1 you can find the lay-out of the SIERA integrated treatment system with a total surface of approx. 2000 sqm.

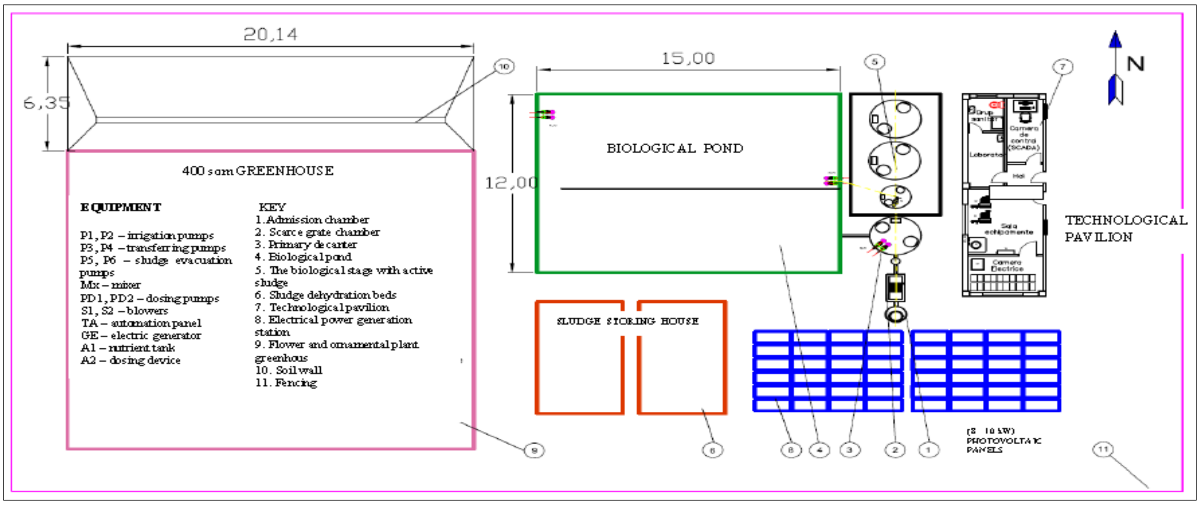

Figure 1. Lay-out of the integrated purification system.

The wastewater treatment plant will combine the technology of natural treatment in biological ponds with biological treatment with active sludge. The biological stabilisation ponds perform pre-treatment, so that the nourishing substances needed by plants, that is nitrogen and phosphorus, may be used as fertilizers by the irrigation system (Crites & Tchobanoglous 1998).

The preservation of the system autonomy supposes the reduction of the heat losses and the compensation of the losses by the natural accumulation of direct sunlight, by inertial mass photovoltaic accumulators, or indirectly, by the aerobic composting of the organic waste materials resulted from the wastewater treatment plant and from the greenhouse.

The assessment of the amount of radiating solar energy sent out in the area where the autonomous system is placed was used to dimension the optimal systems of photovoltaic generators that can be technically implemented. The characteristic consumption curve for the entirety of the equipment that will operate within the autonomous integrated system will ensue from the selected photovoltaic generator and the electrical power requirement. This characteristic curve was then optimised, thus resulting a homogeneous consumption curve, without great variations from one hour to another and with a low load between 4 and 5 o'clock, exactly when the battery energy is almost finished and right before the photovoltaic system begins producing energy. The emergency lighting was also improved. It is the lighting system with indicator lamps that was chosen. These lamps have advantages in four major fields : efficiency, service life, long-lastingness and low maintenance costs.

An emergency electric generator set was integrated in the photovoltaic electrical generator for extreme situations (Tomescu & Tomescu 2008).

The automation and monitoring plant is composed of the following sub-assemblies:

- control cabinet;
- transducers group: transducer for the O_2 dissolved in the water, transducer for the flow rate of the purged water, transducer for the pressure of the blower air, humidity transducer, temperature transducer;
- programmable automated device;
- acquisition interface;
- GSM modem;
- PC for displaying and monitoring.

The envisaged functions are: to monitor the level of the used water in the biological pond, to automatically control the electrical equipment, to point out the appearance of flaws on each and every circuit, to modify and to adjust the prescribed operating parameters.

A system of continuous monitoring in real time and of transmission of the wastewater treatment process parameters to the operator’s room is put in place for monitoring and improving the operating conditions and for diagnosing the functioning of the autonomous integrated wastewater treatment system.

The system monitors: the water flow rate upon the exit from the wastewater treatment plant, the water level in the pumping tank, the water level in the biological pond, the concentration of oxygen dissolved in the water within the biological stage, the operation of the blower and the soil humidity.

All the sub-assemblies described above are taken in charge with by the control cabinet, which contains a programmable automated device that processes the signals received from the transducers and issues the corresponding orders.

The plant is designed to function incessantly and automatically.

The wastewater treatment plant with a biological pond and active sludge**.** The selected technology combines natural purification with the biological treatment with active sludge. This solution reduces the consumption of electrical power considerably and provides the valorisation of the nutrients – nitrogen and phosphorus – from the used water and the sludge.

The applied purging technology aims at efficiently removing the suspension matters, the organic substances, the elements with a eutrophising character (nitrogen and phosphorus) till complete treatment, as well as at ecologically processing and eliminating the created sludge – primary sludge and active-secondary sludge, while mineralising and dehydrating it. In order to optimise the electrical power consumption of the station one proceeded at a preliminary dimensioning on purging stages, in two variants: without a natural treatment stage and with a natural treatment stage. Thanks to these optimisations one arrived to a homogeneous consumption curve without ample variations from one hour to another and with an optimised maximum consumption of 1.6 kW h^{-1}.

The optional biological stabilisation ponds pre-purge and disinfect the water, so that the nourishing substances needed by the plants – nitrogen and phosphorus – could be used as fertilizers by the irrigation system. Where floating macrophytes are cultivated in the stabilisation ponds in certain periods of the year, the excessive concentrations of nitrogen and phosphorus can be mitigated (Crites & Tchobanoglous 1998). Stages are descripted below.

The mechanical treatment plant is composed of:

- a wastewater admission chamber: it receives the wastewater from the sewerage system and sends it to the canal fitted with a grate for separating the solid matters. It is also endowed with an overflow orifice;
- solid suspensions separation canal – complete with a scarce grate and a container for discharging the retained solid matters;
- primary decanter: it retains the fine suspensions. Endowed with a sludge evacuation pump.

The stabilisation pond : a two-compartment soil tank rendered waterproof by a film, with a homogenisation, equalisation and natural pre-purification role and with a mixed aerobic – optionally anaerobic operation. The pond is equipped with the following pumping stations:

- the irrigation waters pumping station: it sends the pre-treatment water separated from the rough and fine suspensions, to the greenhouse. 1+1 submersible pumps with a flow rate of 10 cm h^{-1} at 30 mCA will be mounted;
- the pumping station for transferring purposes: it sends the pre-treatment water toward the biological stage of treatment with active sludge. 1+1 submersible pumps with a flow rate of 5 cm h^{-1} at 6 mCA are mounted in the tank.

The biological stage with active sludge: is composed of 3 partially underground, fabricated insulated tanks. The first tank, for the anoxic operation, will be fitted with a 0.55 kW blender and with air dispersion spreaders. In this tank, the concentration of dissolved oxygen will not exceed 0.2 mg L^{-1}. It will provide water denitrification. The second tank, with an aerobic operation and whose role is to nitrify and reduce carbon and phosphorus, will be equipped with air dispersion spreaders for providing a minimal concentration of dissolved oxygen, namely around 1.5 mg L^{-1}, and with air pumps for recirculation. The third tank, with the role of secondary decanter, will be complete with excessive sludge recirculation and evacuation pumps and with purged water discharge grooves.

The oxygen needed for the aerobic biological processes will be provided by a source of air: 1+1 air blowers, out of which one will have an adjustable rotation speed.

The sludge dehydration stage: it encompasses two sludge dehydration platforms of approximately 20 m^3, covered with canopies. The tanks are endowed with drainage tubes in sand and gravel beds and with a water discharge orifice in the wastewater admission chamber. The sludge that is to be stored will originate from : the sludge from the primary decanter, the excessive active sludge from the secondary decanter and the decanted and stabilised sludge periodically evacuated from the biological stabilisation pond. The flow rate measuring stage will be a chamber where a Parshall canal complete with an ultrasonic sensor for measuring the flow rate is installed and which will measure the flow rate up to 6.22 L s^{-1} (22.4 m^3 h^{-1}).

The technological pavilion: it is a 14.0 x 4.0 x 2.8 m sized building. It will be insulated and fitted with insulated doors and windows, an electrical installation for indoor and outdoor lighting and with one-phase and triphase plug sockets. Its compartments will be the equipment room, the controller room, the electric room, the laboratory and the rest-rooms. The nutrient solution dosing plant, the compressed air station, the equipment of the electric generator, the electrical power accumulation system and the station automation and control system are installed in the equipment room.

The green energy producing and storing plant. The plant will be dimensioned for the 230-380 V 50 Hz voltage and will comprise:

- the photovoltaic generators;
- the d.c. electrical power storing system;
- the solar chargers;
- the system of converting the direct current into alternating current;
- the installation of protection against electrocutions and short circuits;
- the earthing protection installation.

The photovoltaic solar panels are composed of modules (Figure 2). A series of modules form several metre panels. These panels are plain and can be mounted at a fixed South exposure angle or on a sun tracking device that enables the capture of the maximum sunlight within a day. Several interconnected panels will provide electrical power for supplying the wastewater treatment plant and the greenhouse irrigation and heating system (http://www.bizoo.ro/firma/ecovolt/vanzare/976886/sisteme-backup-energie-electrica).

Figure 2. Photovoltaic solar panels.

The covered surface will be approx. 75 sqm and the installed capacity will be 10 kW. The energy storing and transforming elements will be mounted in the technological pavilion. The solar power available for the Transylvanian area averages around 6 kW/sqm/day in July and 1.5 kW/sqm/day in December.

The photovoltaic generator will be made of 48 panels with a 240 Wp power, linked in parallel in series of 3 and connected at the entrance of each solar charger.

The d.c. electrical power storing system is composed of 24 batteries (U = 12 v and I = 250 A) with a serial interconnection, in order to obtain a 48 V voltage. The energy stored in the storing system will be 36 kW.

The solar charger controls the flow of energy generated by the solar panels in order to correctly charge the storing group (http://ro.scribd.com/doc/153135018/Professional-Handbook-Romania-Incalzire-Solara).

This one has an integrated system for tracking the maximum power point (MPP) that guarantees the obtaining of an amount of energy by 15-30% greater than in case of the utilisation of the shunt-type classical chargers.

The system of converting the direct current into alternating curent takes over the energy stored in the storing group and converts it into an alternating current energy, which it then brings to the parameters needed to the control and tracker acting system, that is Un = 230 V and the 50 Hz frequency. The system is also complete with an additional entrance for the connection of another source of electrical power (the generating set, the energetic system), for the consumers' electrical power supply could be continue in case that the weather conditions do not allow the production of electrical power from a solar source. These data enabled the optimisation of the photovoltaic energy production curve with the consumption one of the equipment within the autonomous integrated system for the wastewater treatment and the results can be seen under a graphic form in the Figure 3.

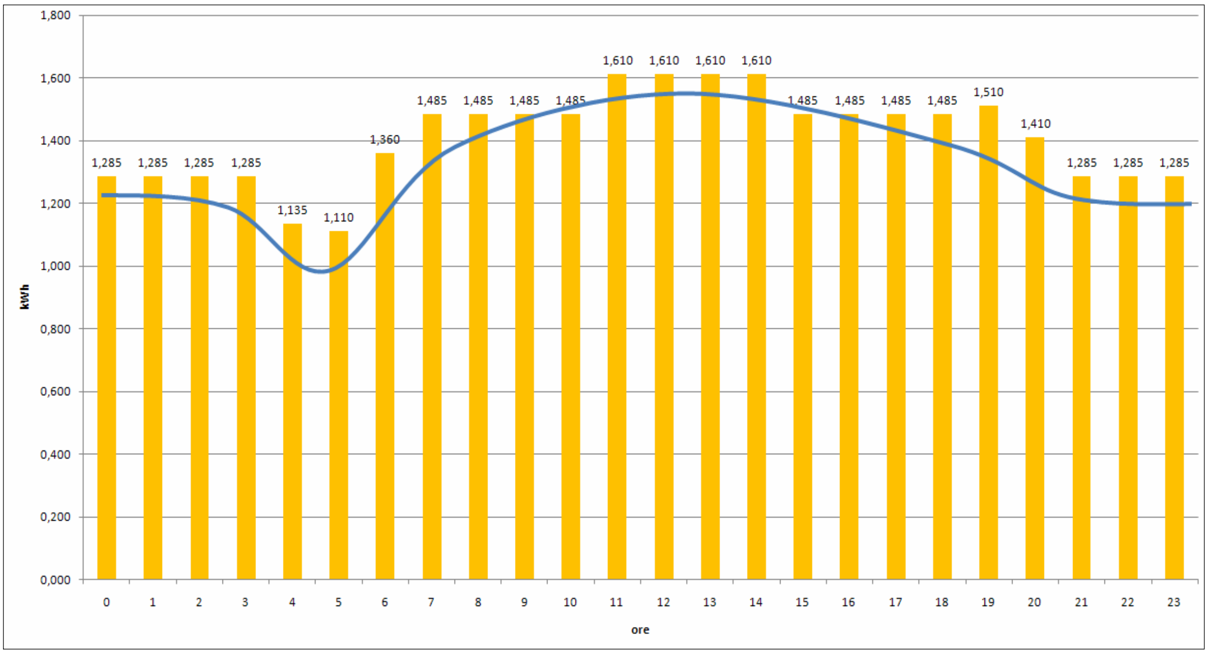

Figure 3. The characteristic consumption curve corresponding to the pieces of equipment of the autonomous integrated system for wastewater treatment – photovoltaic system supply.

After this optimisation, the equipment operation is very good from the point of view of the photovoltaic system, because the consumption peak is reached between 11:00 and 14:00, being significantly lower than the initial situation, of approximately 1.6 kWh.

This enables the right dimensioning of the photovoltaic system and the operation of the autonomous integrated system for wastewater purification exclusively from photovoltaic energy, without the necessity of starting on the generating set in the months when the values of the solar radiation are high.

The necessary additional heat can be obtained from other methods, too, be they natural or modern, by the direct or indirect accumulation of solar energy. The heating variants studied are: a) with an inertial accumulator (with berm and a water-wall); b) with natural heat compensators (by Bokashi or HeatGeen composting).

a) The inertial heat accumulator. By storing and releasing alternative heat, the thermal mass mitigates the extremes to the temperatures during the day. In the areas with a mild/hot climate, if there are considerable variations of temperature between day and night (‘diurnal’ variation), the heat is absorbed during the day and then released in the evening, when the excess can be evacuated by natural ventilation or it can be used for warming up the premises when the temperature drops. The entire process can then be repeated the following day (Figure 4).

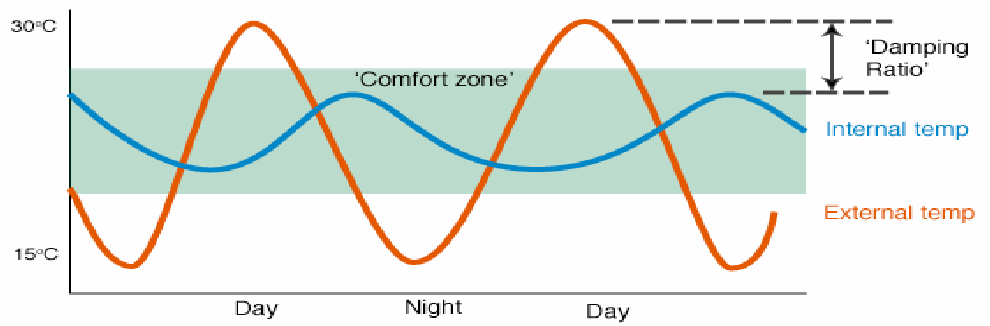

Figure 4. The temperature storing-releasing process.

At present one has elaborated an efficient method of building South-oriented water-walls and a shadowing system during summer.

Adequately shadowed water-walls can function as the air conditioning plants in summer. They improve especially the micro-climate of the greenhouses with a low fire capacity.

Economically speaking, the key problem is the price of the containers filled with water. One sqm of wall needs one container with the diameter of 16 cm and the height of approximately 230 cm. When executed from a PET sheet by welding, the market price for one piece should not exceed RON 20, which represents RON 50/m^2. At this price, the cost for erecting a water-wall would not exceed those of a typical wall with a mineral wool structure.

The South-oriented partitions have a positive energetic balance, even during the 2 coldest months of the year. As for the 4 months of winter, the excess of energy from 1 m^2 enables the compensation of the 4 m^2 losses of traditional partitions on a 0.2 W/m^{2}K coefficient. This type of wall can accumulate from the sun 80% of the energy needed for heating buildings, with a slight increase of the costs for erecting the walls (or without any increase).

The maximum value of the heat transfer coefficient for the separation layers in case of the water pipes and at the exterior, according to which the monthly thermal balance in the entire partition is determined, is positive (Figure 5).

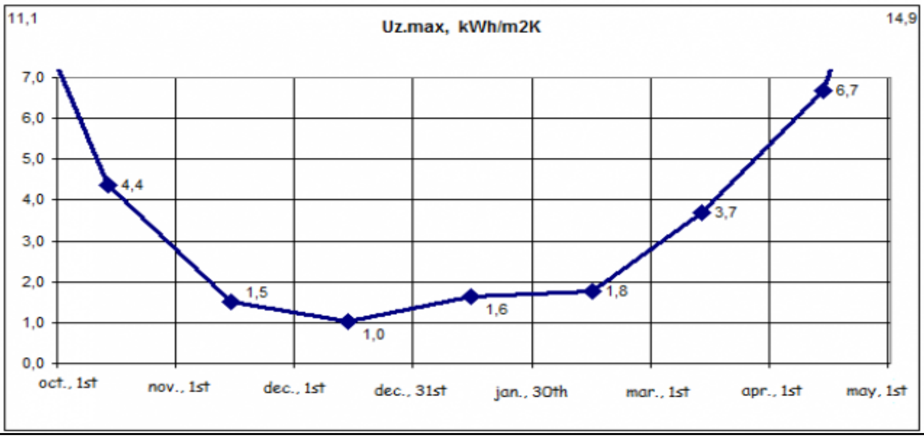

Figure 5. Heat coefficient variation.

b) Natural heat compensators (Act no. 220/2008). Composting means the totality of the microbial, biochemical, chemical and physical transformations that the organic, vegetal and animal waste materials undergo from their initial state till they reach various stages of humification, which is a state qualitatively special as compared to the initial one, characteristic to the newly created product called compost.

There were three main phases identified for the composting process :

- phase 1 – the mesophilic fermentation stage, characterised by the increase of the bacteria and of the temperatures between 25-40°C;
- phase 2 – the thermophilic stage, where we deal with the bacterias, the fungi and the actinomicets (the first level of the consumers) at a 50-60°C temperature, decomposing cellulose, lignine and other resistant materials; the upper limit of the thermophilic stage can be 70°C and the high temperature must be preserved at least one day in order to ensure the destruction of the pathogenic and contaminating agents;
- phase 3 – the maturation stage, where the temperatures get stabilised and certain fermentations continue, converting the degraded material into humus by condensation and polymerisation reactions;
- the last goal is to produce a stable material that can be assessed from the standpoint of the C:N ratio; the well-composted materials have a low C:N ratio: for instance, the C:N ratio can drop from 30 (the beginning of the composting process) to 15 in the mature compost (http://ecology.md/md/section.php?section=ecoset&id=10333(heatingby composting).

During active composting, the aerobic decomposition generates carbon dioxide and water vapours. There are countless factors that affect the appearance of the smell: the amount of oxygen in the pile, the characteristics of the materials subjected to composting, the initial pH of the mixture and the materials used as additives. Even though there is a good supply of oxygen (obtained by diffusion, disturbance or forced aeration), certain big or small bags still remain in the composting pile, the process being carried out under anaerobic conditions in these bags. The utilisation as an accelerator for the efficient composting of “friendly microorganisms” - lactic bacteria – eliminates this shortcoming. The concept of "friendly microorganisms" was developed by the Japanese horticulturist Teruo Higa, from the Ryukyus University within the Okinawa Prefecture (Okinawa, Japan). In 1970, he reported that a combination of approximately 80 different microorganisms was capable of positively influencing the organic matter under decomposition. Higa invokes a "dominating principle" for explaining the effects of the "efficient microorganisms": he claims that the three groups of microorganisms that exist can be divided into: "positive microorganisms" (regeneration), "negative microorganisms" (decomposition, degeneration) and "opportunistic micro-organisms". In each environment (soil, water, air, the human bowel), the "positive" - "negative" ratio amongst the microorganisms is critical, because the opportunistic microorganisms follow the trend of regeneration or degeneration. Consequently, Higa thinks that the offered environment might be positively influenced by its supplementation with positive microorganisms (http://www.envismadrasuniv.org/pdf/em.pdf).

The efficient microroganisms, which were developed industrially and marketed on an EM technology, is a trademark term now often used for describing a patented mixture of 3 or more types of mainly aerobic or anaerobic organisms, the term being initially marketed as EM-1™. It is used as a microbial inoculant, however nowadays it is marketed by a series of companies under various names, each one with its own mark.

The Stefan-Boltzmann law is used to calculate the amount of radiating energy produced by any hot object in a cold environment (http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/stefan.html).

In its simplest form it can be described as follows:

$$Q = \sigma * 4(T_1 - T_2) * A$$

where:

- the temperatures are T_1 – the temperature of the radiating object (1), T2 – the temperature of the surrounding surfaces (2);
- A is the surface of the radiating object;
- σ is a constant, termed the Stefan-Boltzmann constant, which is 0.1713×10^{-8} Btu/m^2/hour.

When 0.45 kg of glucose is decomposed, it chemically needs approximately 0.5 kg of oxygen for the reaction to take place. Since the air only has 1/5 oxygen, it means a need for 2.5 units of air for consumption purposes. This reaction then gives birth to 0.7 kg of carbon dioxide and 0.27 kg of water. The air is around 2 m^3.

Since photosynthesis initially brings forth glucose, all the other organic materials are later on made of glucose and we suppose that other organic matters are very close to glucose in their biochemical reactions. If we mostly use straws,herbs and weeds, we could suppose that the fermentation reaction takes place at a real temperature of 60°C for the bacteria and that the real temperature of all the walls is 50°C. We use the Stefan-Boltzmann law to calculate that each square metre of material should generate a radiation of around 29 Btu hour^{-1}. Consequently, each square centimetre would be the creation of 29/144 or 0.20 Btu hour^{-1}.

If we mostly use wood chips, we will suppose that the real temperature for the bacteria under such conditions is 50°C and that the real temperature of all the walls is 40°C. We use the Stefan-Boltzmann law to calculate that each square metre of material should generate a radiation of around 25 Btu hour^{-1}. Consequently, each square centimetre would be the creation of 25/144 or 0.18 Btu hour^{-1}.

The greatest factor is the total surface that can interact with the oxygen, therefore the heat appearance and radiation far away, as well as the global temperature of the activity have additional effects.

This also explains why a stove only needs a fraction of square metre of firewood all the time, but we need to have more square metres of decomposition surface for producing similar amounts of heat energy.

For a standard decomposition rate of approximately 2.25 kg of material per hour at a maximum of 5.0 kg per hour, this will give rise to around 45,000 Btu hour^{-1} (100,000 Btu hour^{-1}.) of heat. Furthermore, we can calculate the amount of air needed and the evacuation one ruled out at these rates of decomposition. Approximately 12.6 moles-gram of chemical reaction take place per hour. The five kilograms of glucose combined with approximately 5.3 kg of oxygen from the admission air (13 cm needed) give birth to around 7.3 kilograms of carbon dioxide and around 3 kg of water (water vapours).

If we use the com posting of dry straws under the form of wet blocks (bales) with the volume of 0.15 cm and the weight of approx. Five kg, each of them will generate around 103,000 Btu, namely around 30 kW. Depending on the amount of air accepted in time and on humidity, this heat is released for longer or shorter periods of time. Forty five days of aerobic fermentation entail a daily released amount of approx. 0.66 kW or 0.028 kW/h, at an outdoor temperature of maximum 30^{o}C. For 5 kW/h we need around 180 bales.

By the Bokashi-type aerobic composting, the amount necessary for a 90-day (3 months of winter) heating was estimated at around 1.8 tons of material to be composted. In the HeatGeen system, for 5 kg of dry material consumed in one hour, approx. 5 kW/h of heat are obtained (http://www.compostguy.com/bokashi-resource-page).

Greenhouse for water and sludge reutilisation. Our goal is to make a greenhouse fitted with an inertial heat accumulator that uses the natural resources, in order to provide a medium lighted warm stable atmosphere for producing flowers, as well as ornamental and technical plants all throughout the year, plus the localisation of the 0.5-1.0 m cultivation area underground and the solar radiation capture and storing during the day (Figure 6).

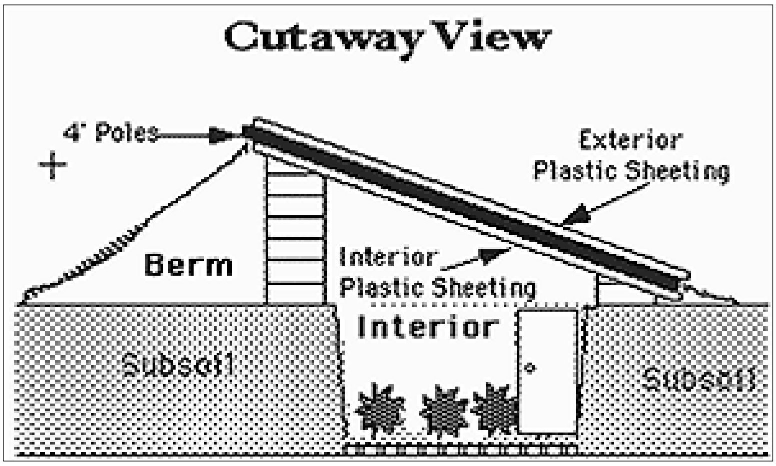

Figure 6. Greenhouse scheme.

The useful surface for water and sludge reutilisation for fertilisation purposes for the 500 equivalent inhabitants purging station will be 400 sqm, with the possibility of extending it up to 2000 sqm and to use the water resource for field irrigation.

The irrigation plant will comprise:

- the pre-treated water pumping station;
- the network of distributing water into the soil;
- the dispersion system.

As for flowers, carnations may be planted, which are perennial, can blossom at low temperatures, of 10-12^{o}C (in winter) and their yield can be 150-250 stalks/sqm and year (http://cursuri-imapa.ucoz.ro/_ld/0/3Curs_Agrotehnic.pdf).

The stabilised, naturally dehydrated and composted sludge will be used for improving the soil quality at the beginning of a plant growth cycle. For an efficient composting method, it is the Bokashi one that will be tested.

Below you can find an excerpt of the data linked to the construction and the operation of a Walipini greenhouse, which is autonomous from the thermal and solar point of view:

- for compensating the heat losses during winter, the construction is subterranean, at a 1.5-2.0 m depth, in order to take over the heat at the +10^{o}C average temperature of the soil;
- it is used an an inertial solar heat accumulator thanks to the earth walls, especially the Northern wall, which is higher and bigger;
- as additional inertial solar heat accumulators, it uses water tanks painted dark, used as a system of pre-heating the irrigation system;
- it is accurately oriented according to the direction of the sun at the winter solstice, in order to enhance the solar radiation absorption efficiency;
- it takes into account the solar rays radiation angle for the construction of the roof;
- it uses an efficient natural ventilation system;

- it uses a water drainage system, which is both interior – for regulating the greenhouse atmosphere humidity and the soil humidity – and exterior – for an efficient protection against abundant precipitations.

The location of the greenhouse in low areas, near the wastewater treatment plant, with a high level of the phreatic layer, calls for a supraterranean construction able to use part of the principles of construction of a Walipini greenhouse; the additional necessary heat can be obtained by other methods, natural or modern, corresponding to the principles of the architectural design for solar houses ("solar house") and passive houses ("pasiv house"). The application of the natural heating methods by building a dim of earth at the Northern wall of the greenhouse or a system of heat mass accumulator by using the irrigation water, the additional utilisation of the natural heat obtained by aerobic composting, innovating systems of additional coverage of the soil cultures during freezing cold winter nights, in order to maintain a minimal temperature of +5^{o}C during the night, as well as the greenhouse orientation to the N-S direction will be aimed at.

Station operation. The selected technology combines natural treatment with the active sludge biological purification. This solution considerably reduces the consumption of electrical power and provides the valorisation of the nutrients – nitrogen and phosphorus – from the wastewater and the sludge.

The applied mechanical and biological purging technology aims at efficiently removing the suspension matters, the organic substances, the elements with a eutrophising character (nitrogen and phosphorus), at the complete treatment and at ecologically processing and disposing of the created sludge – primary and active-secundary sludge, along with its mineralisation and dehydration.

The pre-treatment water accumulated in the biological pond and the mineralised and dehydrated sludge on the sludge beds will be used for irrigating and fertilising the greenhouses related to the station. The reduced consumption of electrical power is due to the photovoltaic electric generator.

The domestic wastewater are separated from the suspension rough solid objects in the scarce grate. The suspension materials are separated by the flowing of the wastewater through the grate and they are periodically evacuated into the discharge container, whereas the water without rough suspensions will flow into the primary decanter, where the fine suspensions are separated. From here the water reaches the biological stabilisation pond, where it gets homogene, even (the flow rates become equal) and naturally pre-purged for 10-20 days. Given that during winter the pond depth does not enable an aerobic, not an anaerobic treatment, a dose of lime is necessary in this time of the year for reducing the anaerobic fermentation and eliminating the smell. In addition, the water pH increase leads to the enhancement of the denitrification efficiency in the second stage of treatment. The water from the pond will be used for irrigation purposes by maximum 80% (20% of the water being needed for keeping the biological treatment stage with active sludge set on foot). The biological stage will be able to purge the entire flow rate when the irrigation is not necessary, irrespective of the greenhouse operation.

From the pond, the water is pumped in the anoxic treatment tank within the biological stage with active sludge, where it gets mixed with the recirculated water from the secondary decanter for the partial treatment of the organic carbon and with the recirculated water from the aerobic tank for mitigating the organic nitrogen. From here the water flows freely in the aerobic tank, where the final treatment takes place, after which it gets separated from the active sludge in the secondary decanter.

Purged water discharge is made through a flow rate measuring manhole. In order to measure the flow rate of the purged water discharged in the biological pond, a Parshall-type flow meter will be foreseen for measuring purified waters. This flow meter is equipped with an ultrasonic sensor for measuring the water flow rate.

The biological purging technology provides quality treated water, as per NTPA001/2002.

The connection of the electrical power to the envisaged point is made from the 10 kW photovoltaic generator. When the luminous energy drops under 1,000 W/sqm for a longer period of time and the entire stored energy is used, the supply from the autonomous electrical generator is proceeded at. The distribution of the electrical power to each consumer will be made from an electrical panel fitted with (triphase and monophase) force circuits and circuits for lighting the wastewater treatment plant indoors and outdoors.

The entire purging process is monitored and controlled from a panel endowed for a 10 kW installed power. The actual necessary power is approx. 5 kW (a blower, a transferring pump and possibly a nutrient dosing plant).

Results and Discussion. In order to optimise the consumption of electrical power of the station, a preliminary dimensioning on treatment stages was performed, in two variants: without a natural treatment stage and with a natural treatment stage. These optimisations led to a homogeneous consumption curve without great variations from one hour to another and with a 1.6 kW h^{-1} maximum optimised consumption.

The optional biological stabilisation ponds perform water pre-treatment and disinfection, so that the nourishing substances needed by plants – nitrogen and phosphorus – could be used as fertilisers by the irrigation system. In the variant where the stabilisation ponds are cultivated with floating macrophytes in certain periods of the year, the excessive concentrations of nitrogen and phosphorus can be reduced.

The preservation of the system autonomy supposes heat loss reduction and loss compensation directly, by the natural accumulation of sunlight by inertial mass photovoltaic accumulators, or indirectly, by the aerobic composting of the organic waste materials resulted from the wastewater treatment plant and from the greenhouse.

The assessment of the amount of radiating solar energy sent out in the area where the autonomous system is placed was used to dimension the optimal systems of photovoltaic generators that can be technically implemented. The characteristic consumption curve for the entirety of the equipment that will operate within the autonomous integrated system will ensue from the selected photovoltaic generator and the electrical power requirement. This characteristic curve was then optimised, thus resulting a homogeneous consumption curve, without great variations from one hour to another and with a low load between 4 and 5 o'clock, exactly when the battery energy is almost finished and right before the photovoltaic system begins producing energy. The selection was for a system composed of 48 290 W 24 V modules of the PV-type - Canadian Solar, Inc. (CSI) and of a storing unit with a 1500 Ah rated capacity, comprising 24 accumulators with a 250 Ah capacity. The emergency lighting was also improved. It is the lighting system with indicator lamps that was chosen. These lamps have advantages in four major fields: efficiency, service life, long-lastingness and low maintenance costs.

An emergency electric generator set was integrated in the photovoltaic electrical generator for extreme situations.

A description of the Walipini autonomous greenhouse was carried out, in order to understand the advantages and the disadvantages of building this greenhouse in our climate area. In the limited conditions of placement, with a high level of the phreatic layer, without the possibility of burying the greenhouse, the possibility of applying methods of compensating the disadvantages by supplement-ing the greenhouse with mass natural heat compensators and by aerobic composting with direct thermal transfer or by indirect transfer by using water as a thermal agent was studied (http://www.the-meal.net/graph/manuel_walipina_benson.pdf).

The system monitors: the water flow rate upon the exit from the wastewater treatment plant, the water level in the pumping tank, the water level in the biological pond, the concentration of oxygen dissolved in the water within the biological stage, the operation of the blower and the soil humidity.

All the sub-assemblies described above are taken in charge with by the control cabinet, which contains a programmable automated device that processes the signals received from the transducers and issues the corresponding orders. The plant is designed to function incessantly and automatically.

The integrated system will be composed of: a mechanical-biological purging station with active sludge and biological ponds, a green energy catching and storing station and a greenhouse.

The wastewater treatment plant will combine the technology of natural treatment in biological ponds with the biological treatment with active sludge. The biological stabilisation ponds perform pre-treatment, so that the nourishing substances needed by the plants – nitrogen and phosphorus – could be used as fertilisers by the irrigation system.

The green energy producing and storing plant will encompass photovoltaic solar panels and will supply the purging station and the greenhouse with electrical power.

The greenhouses for water and sludge reutilisation will use 20-100% purged water and 100% sludge and will produce flowers, ornamental plants and water-loving technical plants. They will be equipped with a high performance irrigation system and with a heating installation for winter. A benefit around 50-150% of the operation costs (after covering the purification and cultivation expenses) is estimated.

The integrated system will be controlled and monitored by a continuous automation and control plant in real time, which will transmit the parameters of the purification, irrigation and ventilation process into the operator’s room.

It will be designed for 500 equivalent inhabitants and the medium flow rate will be 50 m^3/day and the maximum one 85 m^3/day. The charge in pollutants of the waters upon their entering the wastewater treatment plant will be greater than the provisions of NTPA 002/2002 – quality indicators of the wastewaters discharged in the sewage systems of the human settlements. The flow rate of the treated water will have quality indicators complying with NTPA 001/2002.

The solar panels used to produce the energy needed for the station operation will have the 240 kW power. 48 pieces of them will be necessary.

The greenhouses for flowers and ornamental or technical plants will have an approximate surface of 400 sqm and an automated irrigation system.

System efficiency assessment. Utility consumptions. The consumptions of utilities needed by the purging station for 500 equivalent inhabitants can be found in Table 1.

Table 1

The utility consumption for a 500 equivalent inhabitant station

Utility consumption					
No.	*Utility name*	*M.U.*	*Consumptions*		
			Daily	*Annual*	*Specific*
1.	Electrical power	kWh	31.0	12315	0.365
2.	Drinkable water	m^3	0.25	91.25	0.003
3.	Lime	kg	1.25	456.25	0.013

Annual time fund: 365 days.

Operating costs. The independence of the electrical power is provided by the photovoltaic generator. For 12 lighted hours during summer, the generator will produce 10 x (8 + 4 x 0.6) x 0.7 = 70 kWh/day, which will be enough for the operation of the purging station and of the greenhouses (31 kWh +16 kWh = 48 kWh/day).

In wintertime, the amount of energy produced diminishes by approx. 56%. 36 kWh/day are produced by the green energy (which cover the operation of the purging station), however 48 kWh + 40 kWh = 88 kWh are needed (for the station and the greenhouses with the approx. surface of 2,000 sqm), so a 57 kWh/day deficit (for the greenhouses irrigation and heating) comes out. If the generator gets connected to the electrical network, there appears an overplus of energy of around 5,280 kWh during summer, which will reduce the deficit in wintertime to 13 kWh/day (calculated for 4 winter months).

Total expenses: approx. RON 20/day (RON 15/station + RON 5/greenhouse);

Greenhouse profit: approx. RON 100,000/year;

Net benefit: approx. RON 75,000.

Conclusions. The preliminary assessment estimates the surface occupied by the entire system to be around 2000 sqm. The waste water will be pre-purged mechanically and naturally in the biological stabilisation pond and will be preferentially used for irrigation, part of it being used for the operation of the biological purging station with active sludge in a reduced mode, so that the waste water could be purified entirely where there is no requirement of water for irrigation purposes.

The stabilised sludge, composted by efficient methods, will be used entirely for fertilising the soil. The analysis regarding the system autonomy and efficiency showed a low consumption of electrical power, which was independently obtained from the photovoltaic plant foreseen in the project. By valorising the water and the sludge in the greenhouse adjacent to the purging station, the station and greenhouse operating costs get repaid, a profit ensuing, too. As compared to a classical purging station, for which the maintenance and operating costs are a burden for the local community, the suggested system significantly reduces the expenses and brings forth incomes. Furthermore, the system provides at least 2 jobs. The disadvantage of the system is given by a higher investment cost and by a larger surface needed (by approx. 30-40%).

References

Crites R., Tchobanoglous G., 1998 small and decentralized wastewater management systems. WCB and McGraw-Hill, New York, USA, pp. 609-627.

Rose H. G., 1999 Community-based technologies for domestic wastewater treatment and reuse : options for urban agriculture. IDRC, Ottawa.

Tomescu A., Tomescu I. B., 2008 [The direct conversion of energy]. Matrix Rom Publishing House, Bucharest [in Romanian].

*** The Council's Directive 86/278/CEE regarding the protection of the environment and especially of the soils when purging sludges are used in agriculture, as amended by the (EC) Regulations no. 807/2003.

*** Act no. 220/2008 on the determination of the system of furthering the production of energy from renewable sources of energy.

*** Government's Decision 750/2008 for the approval of the Council's Directive 86/278/CEE regarding the protection of the environment and especially of the soils when purging sludges are used in agriculture, as amended by the (EC) Regulations no. 807/2003 – The Regional State Aid Scheme concerning the valorisation of the renewable sources of energy.

*** http://www.bizoo.ro/firma/ecovolt/vanzare/976886/sisteme-backup-energie-electrica.

*** http://ecology.md/md/section.php?section=ecoset&id=10333(heatingby composting).

*** http://cursuri-imapa.ucoz.ro/_ld/0/3Curs_Agrotehnic.pdf.

*** http://aggie-horticulture.tamu.edu/faculty/hall/ellisonchair/water/b1278.pdf.

*** http://ro.scribd.com/doc/153135018/Professional-Handbook-Romania-Incalzire-Solara.

*** http://www.the-meal.net/graph/manuel_walipina_benson.pdf.

*** http://www.compostguy.com/bokashi-resource-page.

*** http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/stefan.html.

*** http://www.envismadrasuniv.org/pdf/em.pdf.

Received: 21 July 2015. Accepted: 20 September 2015. Published online: 31 October 2015.

Authors:
Mircea Craciun, S.C. ICPE Bistriţa S.A., Parcului Str., no 7, 420035 Bistriţa, Romania, e-mail: craciunmircea@icpebn.ro
Daniela Ignat, S.C. ICPE Bistriţa S.A., Parcului Str., no 7, 420035 Bistriţa, Romania, e-mail: daniela.ignat@icpebn.ro
Grigore Vlad, S.C. ICPE Bistriţa S.A., Parcului Str., no 7, 420035 Bistriţa, Romania, e-mail: vlad@icpebn.ro
Liviu Suciu, S.C. ICPE Bistriţa S.A., Parcului Str., no 7, 420035 Bistriţa, Romania, e-mail: liviu@icpebn.ro
Corina Berkesy, S.C. ICPE Bistriţa S.A., Parcului Str., no 7, 420035 Bistriţa, Romania, e-mail: corinaberkesy@icpebn.ro
Valer Turcin, Splaiul Unirii nr. 313, sect. 3, 030138 Bucharest, Romania, e-mail: vturcin@icpe.ro
Sandor Bartha, ICPE – Centre 6 Bucharest, Romania, e-mail:sandor.bartha@icpe.ro

How to cite this article:
Craciun M., Ignat D., Vlad G., Suciu L., Berkesy C., Turcin V., Bartha S., 2015 Autonomous integrated system for domestic wastewater treatment by reusing water and sludge. Ecoterra 12(3):1-13.