ESTIMATE OF BIOGAS GENERATION IN LANDFILLS USING NATURAL COMPUTATION TECHNIQUES

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Abstract. *Historically people have been using non-renewable energy, which caused a drastic reduction of the natural resource with serious environmental impacts. The production of waste has grown quickly as a result of the consumption and discard culture adopted by the human society after the Industrial Revolution. This culture has led to the emergence of large landfills with serious problems for this same society. Among these problems one can list the generation of greenhouse gases. Nevertheless these gases have a high concentration of methane that can be used as fuel and can be collected by a landfill plant. The purpose of this paper is to find an ideal condition for production of methane from a waste management landfill, relating the methane flow variables, the lifetime of a landfill and the increase of viability of the landfill. For the optimization it was used the Particle Swarm Magnetic Algorithm, that can be applied in multimodal function. It provides great help in the applicability of the model and in the analysis of its viability. This study tries to show that it is possible to do a variety of analysis of the methane generation problem in a landfill and that it is possible with a good model and the natural computation algorithm. These results may increase the viability of the waste management business.*

Keywords*: Electric power generation, biogas, landfill, intelligent agents, natural computation.*

1. INTRODUCTION

Availability of energy sources is critical as a factor for generation of economic growth and development in a nation. In the case of developing countries like Brazil, Russia, India and China (BRIC) with large territorial and/or populations, this factor is critical in terms of stability of industry and commerce because the consequences of energy shortages affect so largely that restrict the most diverse sectors of society.

Energy production from renewable sources has been a key factor for sustainable growth, combining environmentally sound practices for use of these energy sources with the environment. There is a waste generated by food consumption habits of modern society, regarded as a problem for public health and the environment. However, the municipal solid wastes (MSW) are also a source of biomass that have great potential for energy production and therefore could be used to improve the energy matrix.

In developed countries there are plants that burn gases from MSW. These systems are expensive and produce highly polluting gases that must be filtered and controlled. In poor countries, MSW are disposed of in dumps or in landfills, the latter being the ideal model and more expensive, and the first model an environmentally incorrect causing various pollution problems.

Considering the landfill as a suitable model for MSW disposal, the waste deposited there produce gas from the degradation of organic matter (biogas) that is a mixture of several types of greenhouse gases, among which methane (CH4), which is also highly energetic.

For the biogas can be used in power generation, it is necessary to make a study of the quantity of gas that is produced by the landfill. This study takes into account various parameters of the landfill and follows a mathematical model to estimate the biogas production over the years. However it is necessary to improve the estimates to determine the feasibility of the project and attract investors.

This paper aims to use natural computing algorithms for studies of maximizing energy production from a landfill, and to propose a new strategy for future projects in the sector of waste treatment, considering the importance of energy generation from landfill as a management model and, thus, closing the link in the chain of production of energy recovery and waste treatment. The purpose of this study is a change of paradigm in terms of how to manage the waste from a landfill, using as a data source the Bandeirantes Landfill at SP/Brazil, and comparing the energy results from this landfill with the results of this study (energy capacity versus lifetime).

2. LITERATURE REVISION

Landfill sites are prepared to receive MSW, where waste is placed in compacted layers forming cells with an average height of 5 meters and slopes with an inclination. After closed the landfill receive suitable superficial protection by planting grass (Montilha, 2005). In preparing the landfill pipes are arranged horizontal at its base for drainage and treatment of leachate liquid that drains (manure), and vertical pipes to capture the biogas, as shown in Fig. 1.

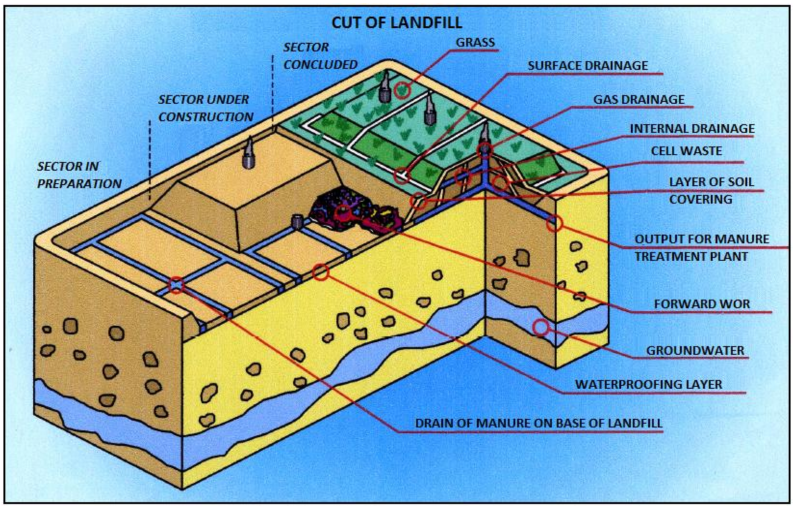

Figure 1. Landfill model. Source Montilha (adapted from Conder, 2005)

The estimated production of biogas from a landfill can be found through some mathematical models, among which Ensinas (2003) highlights: method of simple approach, method for specific countries or regions, methodology for estimating the amount of biodegradable volatile solids remaining and method based on a first-order decomposition rate equation (FODR). According Montilha (2005), each of the above methods shows differences in the results given its complexities and amounts of data they need.

The environmental protection agency of the USA (U.S. Environmental Protection Agency-USEPA) provides on its website the spreadsheet LandGEM (Landfill Gas Emissions Model) based on the FODR. According to the USEPA (1997) this software provides an approximation of emissions from a landfill from empirical data of the landfill. The calculation of methane generation is presented in Eq.(1).

$$Q = Lo.R.(e^{-kc} - e^{-kt}) \tag{1}$$

3. ALGORITHM

The algorithm has the commitment of being faithful to the its fundamental characteristics and only requiring initially the setting of two parameters: the number of employed particles and the maximum number of evolution cycles (Prampero and Romis, 2011).

The proposed initialization is to distribute in a uniform way the particles in the search space. Afterwards, the maximum and minimum radii of each particle repulsion region are calculated based on the number of particles and the size of the search space. The minimum radius is set throughout this work as the thousandth part of the maximum radius. This, naturally, is somewhat arbitrary, but experiments revealed that the performance of the algorithm is not particularly sensitive to this choice.

The repulsion region is important to prevent the particles from becoming excessively close to one another. Nothing happens when there is intersection only between repulsion regions, but, when the algorithm detects that a particle has invaded another's repulsion region, the worse particle (in terms of the cost function) is removed from it. The size of the repulsion region of each particle is calculated during the algorithm execution. Its size is bounded by the maximum and minimum radii, and depends on the values of the cost function: when a particle improves her cost, its repulsion region increases, decreasing otherwise.

In the beginning, the particle moves randomly in the search space until it finds a better point: notice that, on the other hand, a decrease in the cost is not accepted. When a better solution is found, the particle stores it and the direction along which it has moved: in the next step, the algorithm generates the new point on this line. If the new point thus generated is worse than current, two perpendicular points are studied. The best perpendicular point can be adopted if it is better than the current point, and, in this case, the perpendicular line will also be adopted. If any point along the perpendicular line is better than the current, the particle loses the direction and the new point is randomly generated within the repulsion region. In this case, the repulsion region decreases until the algorithm finds a better point than current one.

If the particle is unable to find better points, the radius of its region of repulsion is decreased until the minimum value is reached, which accounts for a refinement of the obtained good solutions. As mentioned earlier, if a particle enters another's region, the particle with lowest value will be taken away along the line of better particle. The size of this position change should be enough to place the particle outside the repulsion region.

However, if the better particle does not have a direction to follow, the worse particle uses its own direction to leave the region, with a sufficient step size. Finally, if both particles have no associated direction, the worse particle will be sent towards the best particle. In Algorithm 1, we find the main structure of the method.

```
Algorithm 1: Magnetic Particle Swarm Algorithm
initialize()
while termination criterion is not satisfied do
    Move particles()        //See Algorithm 2
    Verify confronts()      //See Algorithm 3
end while
```

Let us now consider in more detail each function.

Function Initialize()

This function uniformly distributes the particles in the space of feasible solutions, and calculates the upper and the lower bounds of the repulsion regions. The upper bound of the repulsion region (*ubrr*) is showed in Eq. (2).

$$ubrr^k = \frac{(u^k - l^k)}{2(\frac{m}{n})} \tag{2}$$

where u^k is the upper bound of the search space in dimension *k*, and l^k is the lower bound of the search space in dimension *k*, *n* is a number of dimensions, *k =1,.., n,* and m is a number of particles. The lower bound of the repulsion region (*lbrr*) is showed in Eq. (3).

$$lbrr^k = 0.001.ubrr^k \tag{3}$$

```
Algorithm 2: Move particles()
for each particle do
if(particle has a direction)
    generate one point in this direction
    if( the new point is better)
        store this point
        increase in 10% the repulsion region limited by ubrr
    else
        generate two perpendicular points
        if(the best of them is better than current point)
            store the best of them and its direction
        else
            lose direction
        end if
    end if
else
    generate three points using Eqs.(4)(5)(6)
    if( the best generated point is better than the current point)
        store the best generated point and its direction
    else
        if( never had a direction)
            store best generated point
        else
            decrease in 1% the repulsion region limited by lbrr
```

```
            end if
        end if
    end if
    end for
```

At the beginning, the particle “does not know” where it needs to go, it does not have a direction. Therefore, it walks randomly in the search space. When it finds a better point than the current, it stores this point and defines a good direction. In the next step, the first point to be tested is one along this line (direction). If the new point is better than the current one, it continues walking on this line and the repulsion region is increased. When the particle has a direction, all points are generated inside the particle repulsion region.

When the line/direction is not good, two points on a perpendicular line will be tested. If the best perpendicular point is better than the current one, the new direction is stored. In problems with more than two dimensions, the perpendicular is generated on a randomly selected plane.

When a particle does not know where to move to, it walks randomly as in Eq. (4), (5) and (6).

$$Paux1^{k} = P_i^{k} + \lambda_i^{k} \, \mathrm{Re}\,p\,\mathrm{Re}\,gion_i \tag{4}$$

$$Paux2 = P_i + \lambda \, P_i \tag{5}$$

$$Paux3 = P_i + \lambda \, \mathrm{Re}\,p\,\mathrm{Re}\,gion_i \tag{6}$$

where $k=1,\ldots, n$ and $i=1,\ldots, m$, being n and m as in Eq. (2). $RepRegion_i$ is the repulsion region of particle i. λ is random number belonging to [-1,1], and λ_i^k is calculated for each dimension n.

The difference between Eq. (4) and (6) is that, in (4), for each dimension, a random number is used, and in (6) the same random number is used for all dimensions.

If the best particle of *Paux1*, *Paux2* and *Paux3* is better than the current point, the algorithm accepts the better point and discovers a new line to move; otherwise the repulsion region is decreased.

Algorithm 3: Verify confronts ()

```
for each particle pair do
    if(distance between pair is less than the largest repulsion region)
                    if(the better particle has a direction)
                        move the worse particle in this direction
                    else
                        if(the worse particle has a direction)
                            move it in this direction
                        else
                            move the worse particle in the direction of the best particle.
                        end if
                end if
    end if
end for
```

This function verifies if a particle invades the repulsion region of another. If this is the case, the worst particle is removed from this region. If the best of them has a direction to move, the worst particle is forced to this direction. If not, but the worse particle has a defined direction, then it follows it with a step large enough to place it outside the repulsion region.

Finally, if neither has a defined direction, the worst of them follows the direction of the best particle of all.

3.1. Experiments and results

In this section, the algorithm Magnetic Particle Swarm was applied in a problem of control of the production of methane in a landfill. This algorithm is just one algorithm to be applied in problem of this kind, and it was selected because it already was tested in problems with functions of 1000 dimensions not continuous and not differentiable (Prampero and Romis, 2011a). Therefore this algorithm gives flexibility to the mathematical model of landfill because it can be changed and we can apply the same algorithm on this new model (Kennedy and Eberhart, 2001).

The problem consists in the optimization of the capture of methane in a landfill. The Bandeirantes landfill was studied and it can to capture 122.640.000 m^3 of methane per year, so if production is greater than this figure the surplus will be burned. In this way the production must be very close of 122.640.000 m^3 per year. Therefore we use the model below, according to Eq. (7) and Eq. (8).

$$\mathrm{Pr}\,oduction(year) = L_0 K \sum_{i=1}^{year\_deposit} M_i e^{-(k(year-i))} \tag{7}$$

```
If (Production(year) > 122640000)
    total(year)=122640000 - (Production(year) -122640000)/2;
else if (Production(year) < 120000000)
    total(year)= -100000000;
end
```

$$F(year) = \sum_{i=1}^{year} total(i) \tag{8}$$

where,
year = year of landfill’s life.
year_deposit = year of deposit of waste.
M_i = mass of waste accepted in the ith year (Mg).
L_0= 125, potential methane generation capacity (m3 /Mg).
K = 0.1, methane generation rate (year).

Note that if the production (see algorithm 4) is bigger than 122.640.000, the production will be punished, and if the production is lower than 120.000.000, the production goes to -100.000.00. It is a way to prohibit the production to be lower than 120.000.000.

In the experiments the algorithm used 50 particles and evaluate 1.000.000 times *F*(year). The algorithm can change *Mi* and year to try to optimize *F*(year). The results obtained are shown in the Tab. 1 and graphs below.

Table 1. Deposit of waste (Mg.10^3) by year in Bandeirantes landifill, and the optimization with 12, 15 e 20 years.

Year of deposit	**Year**									
	M_1	**M_2**	**M_3**	**M_4**	**M_5**	**M_6**	**M_7**	**M_8**	**M_9**	**M_{10}**
Bandeirantes	1095	1149	1207	1267	1330	1397	1467	1540	1617	1698
12	9812	933	932	933	933	933	952	916	933	933
15	9811	934	933	933	933	933	933	933	935	932
20	9811	937	930	1006	867	1057	821	932	937	932

Year of deposit	**Year**									
	M_{11}	**M_{12}**	**M_{13}**	**M_{14}**	**M_{15}**	**M_{16}**	**M_{17}**	**M_{18}**	**M_{19}**	**M_{20}**
Bandeirantes	1783	1872	1966	2064	2168					
12	933	4478								
15	932	933	934	934	1677					
20	932	934	1329	583	926	36	19	385	246	0

To compare the results, the sum of waste deposited is 23.628.527 Mg for all cases, and the Bandeirantes landfill has deposited his waste for 15 years.

Figures 2 (a) and (b) show the waste accepted per year and methane per year what happened in the real case of the Bandeirantes landfill.

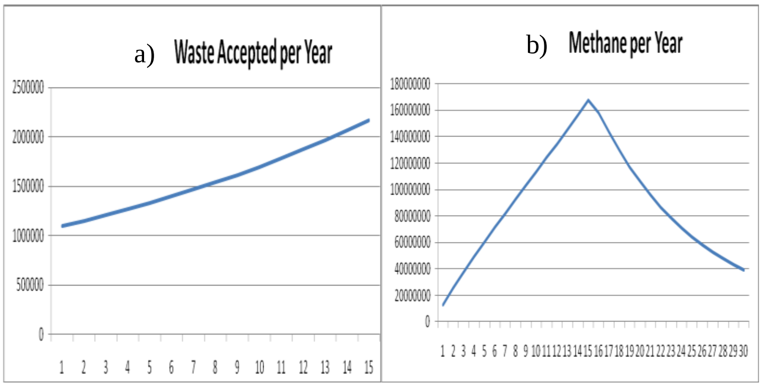

Figure 2. (a)Waste accepted in 15 years of deposit; (b) Methane produced by Bandeirantes landfill

The waste accepted was increased little by little, and the production of methane reached of capture capability of Bandeirantes landfill in year 11 and it cannot maintain this production in year 19. Notice that the production has a peak, and it reached the production of 167.353.975 m^3 of methane in year 15, but as the Bandeirantes landfill can capture only 122.640.000 m^3 per year, the excess was burned. In this case, the system maintains the production of methane over capture capability just for 8 years.

The next graphs in Fig. (3a) and (3b) show the simulations obtained by the application of the Magnetic Particle Swarm Algorithm on the mathematical model for 12 years of deposit of waste.

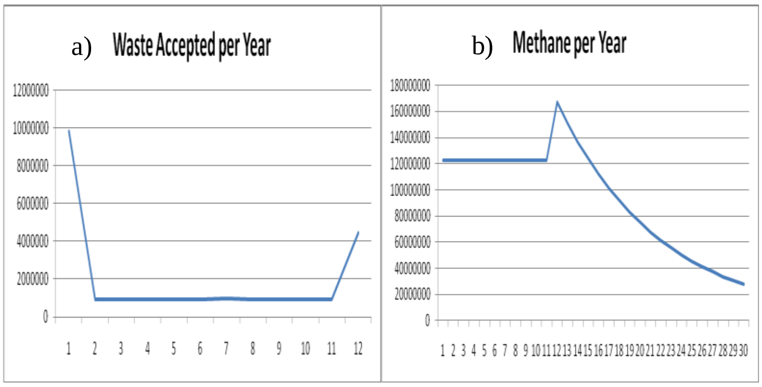

Figure 3: (a) Waste accepted in 12 year of deposit; (b) Methane produced with 12 year of deposit

Notice that the optimization tries to maintain the production of methane very close to the capture capability of Bandeirantes landfill, for this reason the system need a big deposit of waste in the first year. Figure 3(a) shows that there is an excess of waste to deposit in 12 years, because the graph shows the peak in year 12. As show in Fig. (3b), in this case the system maintains the production of methane above the capture capability for 15 years.

Figure (4a) and (4b) are similar to Fig. (3a) and (3b), but now the waste was deposited for 15 years. In this case, the system maintains the production of methane above the capture capability for 15 years.

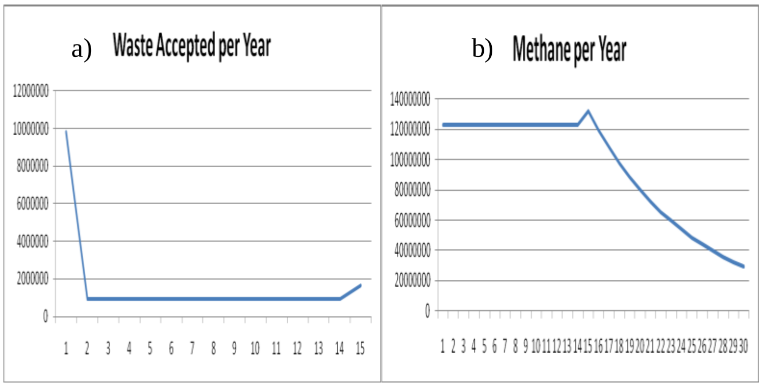

Figure 4. (a) Waste accepted in 15 year of deposit; (b) Methane produced with 15 year of deposit

Figure (5a) and (5b) indicate that the waste were not enough to maintain the production above 122640000 m^3 for 20 years. In this case, the system maintains the production of methane above the capture capability for 15 years.

In all cases the optimization showed that the amount of waste is enough to maintain the production of methane for at least 15 year.

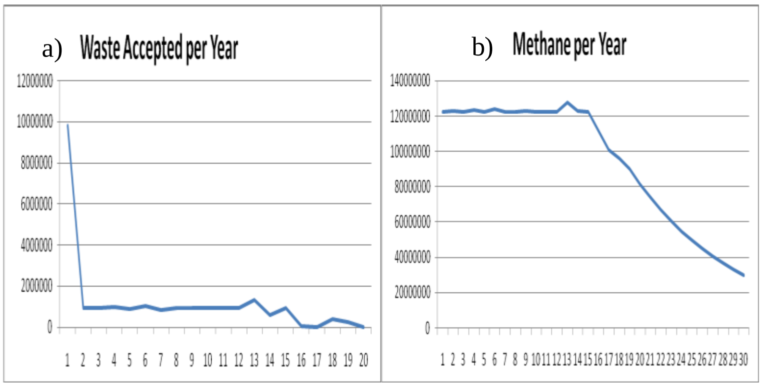

Figure 5. (a) Waste accepted in 20 year of deposit; (b) Methane produced with 20 year of deposit

4. CONCLUSIONS

The optimization method used in this study to calculate the amount of waste is unprecedented and the experiments show that it is possible to control the methane production using the volume of waste deposited, based on a mathematical model. When the plant is being developed, we can calculate the capability of landfill to receive waste and to produce methane, and how much waste will be deposited per year to produce this capability.

With this information it is possible to foresee how much time is necessary to return the money invested. The precision of all these affirmations depends on the quality of the mathematical model used in the simulations.

The results demonstrate the optimization of energy generation from landfills, since its projects are designed for this purpose and together with improved waste management.

As can be seen in the three simulations, the algorithm had a high concentration of waste in the first year and decreased in other years. As the waste is proportional to population growth, the waste management for a single discharge would not be possible with this model. But if we consider more than one landfill, they could make the joint management of waste deposited in these landfills, reaching the results of power generation according to studies.

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