ORANGE PEEL MANAGEMENT CAN MAKE THE SHIFT TO CLEANER SMALL-SCALE ORANGE JUICE INDUSTRIES. A COLOMBIAN CASE STUDY

D.L. Ortiz[1], S Ospina[2], C.E. Orrego[3]

[1]Department of Industrial Engineering, Universidad Nacional de Colombia, Manizales, 170004, Colombia
[2]Department of Chemical Engineering, Universidad Nacional de Colombia, Manizales, 170004, Colombia
[3]Department of Physics and Chemistry, Universidad Nacional de Colombia, Manizales, 170004, Colombia.
Presenting author email: dlortizg@unal.edu.co

Abstract

Purpose: (1) to model mixes of coal and dry OPW incineration, (2) to model the biogas production from orange waste (OPW), and (3) to compare and evaluate these two scenarios, with the current situation of the company from the economic and environmental perspective. **Methods**: The simulation of the energy production was used to compare economically and environmentally the incineration of coal, OPW and mixtures of both as fuel alternatives for a boiler in company extractor of orange juice, located near the city of Manizales, Colombia. In addition, a biogas production was simulated and evaluated. **Results**: Coal incineration had the highest environmental impact. While biogas production shows to was environmentally friendly. However, for small and medium-sized citrus extraction companies, the installation of a biogas production plant is not viable in the near future, due to the high investment costs. It was obtained that the incineration of a mixture of coal (20%) and OPW (80%) was the best option. Due to, this presented a decrease in environmental impact and a reduction in waste disposal costs. In addition, the investment costs are very low (near to 10%) compared to biogas production. **Conclusions**: It is possible to study of the cost of incineration and non-incineration technologies has been undertaken to build on the current evidence base to support the adoption of the appropriate mix and scale of technologies to help manage FLP Procesados the OPW disposal.

Keywords: life cycle assessment, energy, orange waste, industry, economic.

---

1. Introduction

Currently, orange juice is one of the most consumed beverages in the world. During its production, only about half of the fresh weight of orange is transformed into juice; the remaining 50%, corresponds to pulp, peel, and seeds [1]. About 95% of this waste corresponds to peels (OPW), which are a disposal issue for the industry, because their management consumes resources and could pollute air, water and soil.

The use of agro-industrial waste generated in processes is of global interest. In this way, several researchers have focused on its valorization, as a renewable resource for obtaining value added materials like essential oils, pectin, biopolymers, animal feed, activated carbon, enzymes, pollutants adsorbents, fuels and energy, among others [2]. Many of these products have been obtained through small-scale processing technologies and systems. Although contributions to the development of new processes has increased in the last years, there is still a lack of industrial applications because the suggested solutions involve important investments. As its high and rapid volume of processing and because it involves less environmental impact with respect to conventional disposal (landfills), obtaining energy from burning the dried leftover of orange peels has become an attractive alternative the small and medium orange juice plants [3-4].

Based on a case study from Colombian citrus juice manufacturer (FLP Procesados) that burned coal to provide process steam, the main objectives of this research were: (1) to model mixes of coal and dried OPW incineration, (2) to model the biogas production from OPW, and (3) to compare and evaluate these two scenarios, with the current situation of the company from the economic and environmental perspective.

2. *Methodology*

2.1 Materials

OPW was provided by FLP Procesados just after the juice extraction process. This was frozen and stored at -14 ° C in plastic bags for 1 month.

2.2 Methods

Drying calculations were based on the models proposed by [5] and [6]. The mass and energy balances were based on empirical data from various sources, such as previous studies conducted at the National University of Colombia [7] and other countries [8-9]. SuperPro ® Designer Software v 10 (Intelligent Inc.) was used to model both processes.

2.2.1 Incineration

The combustion of carbon, hydrogen, nitrogen and sulphur was assumed to be complete, leading to the generation of CO_2, H_2O, NO_2 and SO_2, respectively. The percentage of excess air excess with respect to the stoichiometric value was fixed at 40%, since this is the value that allows reaching an oxygen concentration of 6% (dry basis) in the combustion gas [8]. Two incineration plants were compared. I) coal incineration; ii) coal + OPW incineration. Both scenarios were modeled taking into account the energy requirements of FLP, both in terms of efficiency. In the incineration of coal mixtures and dehydrated OPW, the maximum ratio of OPW/ coal was 4: 1. The emissions of CO_2, NO_x, SO_2, H_2O, O_2 and N_2 of each mixture of solid fuels were estimated from mass balances. The following assumptions were made (1) the combustion process took place under adiabatic conditions; and (2) in the case of OPW, the flows of NOx and SO_2 were low compared to the other solid fuels.

2.2.2 Biogas production

The simulation was performed using the software SuperPro Designer v 10 (Intelligent Inc.). After placing all the input data, the software automatically calculates mass and energy balances, the flows around each unit process, the amount of heating agent required, the energy requirements and the cost analysis. At industrial-scale, the experimental set-up, consisted of one tank reactor. That was (37 °C) was maintained by means of a thermostatic jacket. The reactor was fed in semi-continuous mode (every 20 days) based on experimental data. A tank was used to store the OPW prior to anaerobic treatment. The generation of methane was also simulated by anerobic fermentation of the OPW. The composition data was based on the review of the literature for OPW in Colombia.

2.2.3 Environmental analysis

The environmental analysis followed the ISO 14040: 2006 standard, using the results of the mass and energy balances of the simulations, and Ecoinvent 3 data sources for the life cycle inventory (LCI). The software Simapro 8.3 was used for calculating the impacts. The life cycle assessment (LCA) study evaluated the main environmental impacts related to the generation of boiler steam by coal combustion and/or OPW and biogas production; the boundary of the system was gate to gate and the functional unit was 1 MJ of energy. The inventory data were based on experimental studies previously published, unpublished experimental data and estimations of the authors, the Ecoinvent database, and personal communications with experts in the field.

2.2.4 Economic aspects

The economic evaluation was based on information of fruit, coal, transport, storage, processing and disposal costs supplied by the FLP Company. The valuations for the investments for the boiler feed system modification to incinerate dry OPW and the facilities for biogas production and upgrading system, were supplied by local companies that provide these services.

3. Results and discussion

3.1 Coal incineration

Currently, the manufacturer uses a coal fired steam boiler. Table 1 gives a summary of the utilities used in the process.

Table 1. Energy requirements of the company

Utilities	**Amount**
Steam [Kg/day]	30754,440
Pressure [psi]	108
Coal [Kg/ day]	4054,200
Ash [Kg/ day]	369
Kg steam/Kg coal	7,590
Kg ash/ Kg coal	0,093

In this scenario, orange peels are wasted and disposed in a landfilling. Figures 1 and 2 present the existing scheme for orange juice extraction and the steam generation processes.

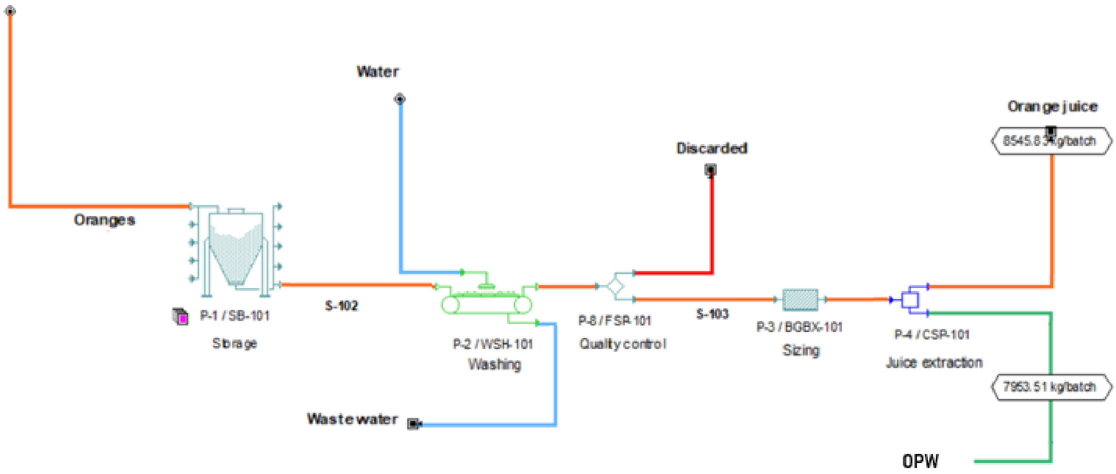

Figure 1. Production of orange juice.

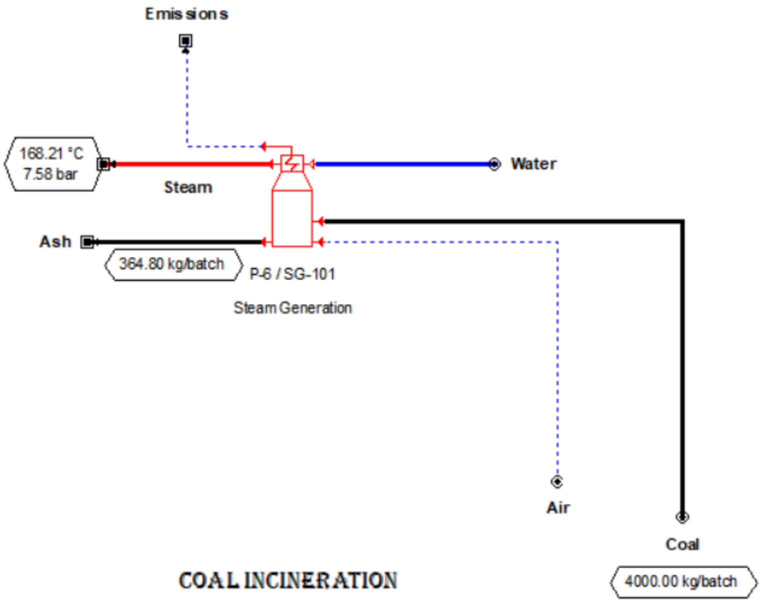

Figure 2. Steam generation.

The relevant fluxes of materials are presented in table 2 and 3. Note that Table 3 data are similar to those provided for the company (Table 1). Different laboratory high value-added options like the extraction and stabilization of bioactive compounds from the OPW are not still economically viable to apply due to the low available raw material volume and high initial investment. Therefore, in this particular case, obtaining energy from OPW becomes an attractive alternative due to its low cost, high and fast processing and because it involves less environmental impact compared to conventional disposal (landfills) and coal incineration.

Table 2. Current situation of company (simulation results)

Batch	Flux [Kg]
Oranges	16666
Discarded	166,66
Orange juice	8545,82
OPW	7953,5

Table 3. Steam generation (simulation results)

Batch	Flux
Steam [Kg]	34421,932
Pressure [psi]	109,93
Coal [Kg]	4000
Ash[Kg]	369
Emissions [Kg]	12689,984

This scenario produces harmful environmental impacts (air pollution, global warming, water pollution caused by the coal mining and processing, etc.) and contaminants that detriment public health. Moreover, the OPW in the table 2, is disposed in landfill send to landfilling and the recent bills have been of 0,077 USD/Kg.

3.2 Coal+OPW incineration

On a basis of 16666 kg of orange / batch, simulation results for co-combustion of dried orange peels and coal are presented in figure 3 and table 4. In this scenario, the OPW left over from juicing oranges are sent to cold press extraction equipment. Spent or exhausted peels are then dried until final moisture content is reduced to about 20%. Finally, dried OPW is incinerated with coal in a boiler, in which hot combustion gas is used to produce steam [10].

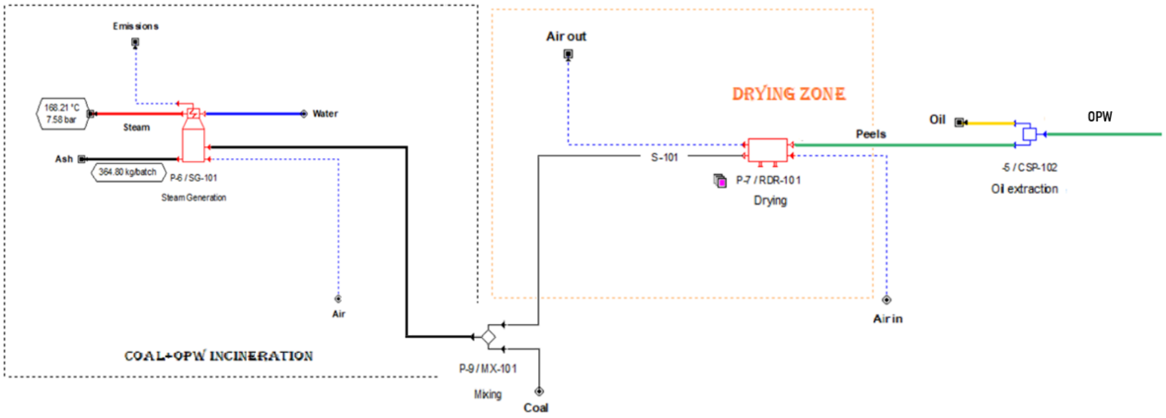

Figure 3. Diagram process of coal+OPW incineration.

According to [11], the energy production from OPW at industrial level is a sustainable practice. This process is capable of converting a potentially polluting organic waste, in a valuable source of benefits (from the sale or self-exploitation of energy) for farmers and agricultural entrepreneurs. The mass balance for this scenario is shown in table 4.

Table 4. Results of coal+OPW incineration

Batch	Flux [Kg]
Orange	16666
OPW	7953,5
Oil	149,68
Peel without oil	7803,83
Dried peels	1950,96
Coal	2483,33
Steam	34228,06
Natural gas for air heating	142,14*
Drying air	35085,5

*Cubic meters

Air drying estimations were done according to [12].

In this case, the essential oil can be sold generating additional profitability.

3.3. Biogas production

The biogas production from WOP was simulated suposing previous extraction of D-Limonene from OPW. The processes diagram is presented in figure 4.

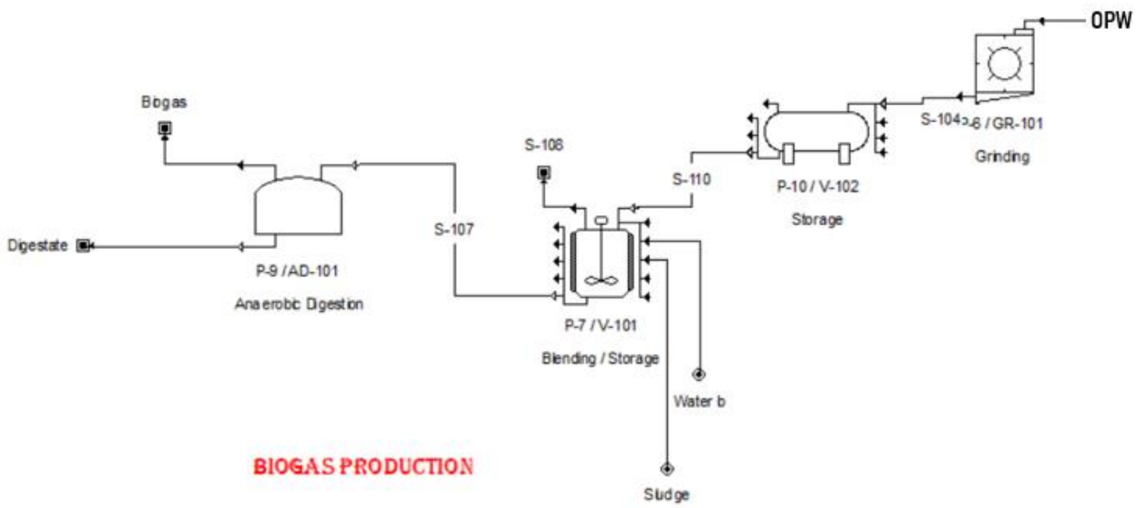

Figure 4. Process diagram of biogas production.

Based on 8545,82 Kg of orange juice, the anaerobic digestor produces 151011,93 m^3 of biogas containing aproximatelly 55% of methane. This amount is sufficient to satisfy the energetic demands of the FLP manufacturer. The calorific value of the obtained biogas was measured as 21,4 Mj / m^3. This excess of produced from biogas can be sold, generating additional income [13]. In addition, after anaerobic mesophilic digestion, the obtained digestate can be used as an agricultural fertilizer [14]. In this way, anaerobic digestion could be considered a sustainable and technically viable way to treat this type of waste. The presence of essential oils in OPW can inhibit the anaerobic digestion, due to this its extraction is recommended by available technologies [8].

3.4 Environmental analysis

Regarding nine impact categories, figure 5 shows the potential contribution to the environmental impact of the evaluated scenarios.

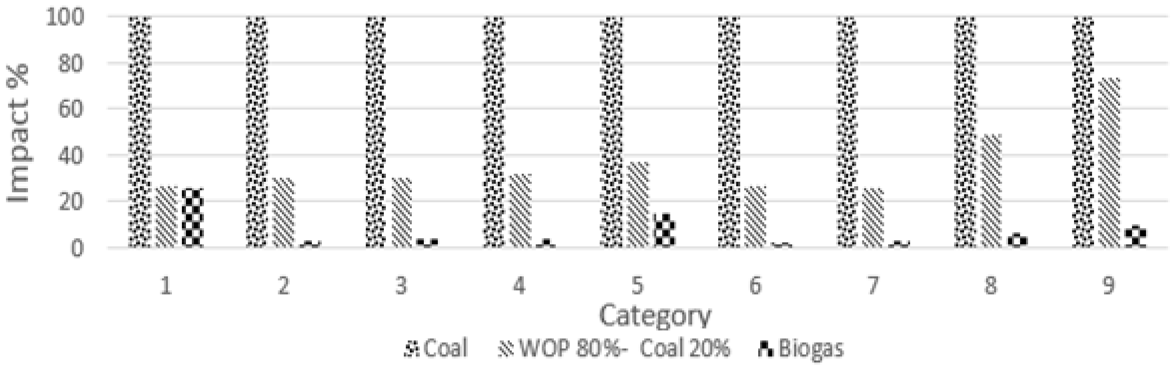

Figure 5. Environmental evaluation of coal incineration; Incineration of 80% WOP and 20 coal and biogas production (Where: (1) Climate change, (2) Ozone depletion, (3) Terrestrial acidification, (4) Freshwater eutrophication, (5) Marine eutrophication, (6) Human toxicity, (7) Photochemical oxidant formation, (8) Terrestrial ecotoxicity y (9) Natural and land transformation).

Steam generation from biogas production can provide significant mitigation of environmental indicators (climate change, ozone depletion, terrestrial acidification, fresh water eutrophication, marine eutrophication, human toxicity, photochemical oxidant formation, terrestrial ecotoxicity and natural land transformation) compared to current coal or coal /OPW incineration mixes. As can be seen, incineration scenarios are the main contributors to environmental impact in the analysis, account for 72% of the total contribution (category number 9); this contribution is due to, at the gas emissions into the atmosphere and OPW disposal in landfills. Finally, the scenario with the lower impact was biogas production (Category number 1).

3.5 Economic aspects

Table 5 presents the summary of the costs generated by coal and coal + OPW incineration.

Table 5. Flux and costs generated by coal and coal + OPW incineration.

Flux and costs of coal incineration				**Flux and costs of coal +OPW incineration**			
	Flux	**Unit cost**	**Total costs**		**Flux**	**Unit cost**	**Total costs**
Methane	0	0,430 USD/ m3	$ -	**Methane**	77,54	0,430 USD/ m3	$ 33
Coal	4054,2	0,077 USD/Kg	$ 314	**Coal**	2686,8	0,077 USD/Kg	$ 208
OPW Disposal	7953,5	0,056 USD/Kg	$ 445	**OPW Disposal**	0	0,056 USD/Kg	$ -
Total			$ 759	**Total**			$ 241

According to the values presented in table 5, it can be seen that, although the consumption of methane is greater in the coal + OPW incineration scenario, it presents minor total costs than the option of coal incineration. This remarkable reduction is mainly due to the disposal cost of OPW.

In the scenery of biogas production, preliminary comparative estimation of the investments required for the combustion of OPW, and the biogas production showed that the second option is economically not advisable for a small juice producer because it involves a large investment in facilities (around US $ 3.5 million). Important cost factors such as the size of the plant, its technical sophistication, the cost of capital, regulatory compliance and biogas purification make this scenario unlikely in the near future for small or medium-sized juice processing companies.

As expected, in the steam generation process, the greater the amount of OPW was used, the lower the environmental impact of the incineration/biogas production of solid fuel, and the lesser the waste management costs. In contrast, costs adjustments of the dryers and boiler of the case study company were low (around US$ 110,000). As mentioned, the company processes 16666 kg /batch of orange, which produce approximately 7953,5 kg /batch of OPW. After dehydration step (after which the OPW reached 20% moisture on a wet basis), there will be available 1950,96 kg /batch of dry OPW. Discounting drying energy, dry OPW offers a surplus that could be used to supply up to 80% of the energy provided by the coal in the current operation of the boiler.

4. Conclusions

A waste that generates an additional cost in the process, logistics problems, storage, and disposal, can be used energetically for generating an important reduction of environmental impact in an orange juice factory.
Although the production of biogas exhibited lowest environmental impacts, compared to the incineration of coal and coal / OPW, the alternative that burnt coal/OPW would be technically, economically and environmentally more feasible, being the 80% WOP and 20% coal mixture the best solid fuel combination.

5. Acknowledgments

The authors acknowledge the financial support of FONTAGRO (Proyecto ATN/RF 16111RG), FLP Procesados and Universidad Nacional de Colombia.

6. References

[1] K. Rezzadori, S. Benedetti, and E. R. Amante, "Proposals for the residues recovery: Orange waste as raw material for new products," *Food Bioprod. Process.*, vol. 90, no. 4, pp. 606–614, 2012.

[2] N. Mahato, K. Sharma, M. Sinha, and M. H. Cho, "Citrus waste derived nutra-/pharmaceuticals for health benefits: Current trends and future perspectives," *J. Funct. Foods*, vol. 40, no. December 2017, pp. 307–316, 2018.

[3] C. M. Santos, J. Dweck, R. S. Viotto, A. H. Rosa, and L. C. de Morais, "Application of orange peel waste in the production of solid biofuels and biosorbents," *Bioresour. Technol.*, vol. 196, pp. 469–479, 2015.

[4] V. Negro, B. Ruggeri, D. Fino, and D. Tonini, "Life cycle assessment of orange peel waste management," *Resour. Conserv. Recycl.*, vol. 127, no. August, pp. 148–158, 2017.

[5] C. E. Orrego, *Procesamiento De Alimentos*. Manizales, 2003.

[6] A. Galvagno, M. Prestipino, V. Chiodo, S. Maisano, S. Brusca, and R. Lanzafame, "Energy Performance of CHP System Integrated with Citrus Peel Air-Steam Gasification: A Comparative Study," *Energy Procedia*, vol. 126, pp. 485–492, 2017.

[7] C. A. Cardona A, J. Ó. Sánchez T, J. A. Ramírez A, and L. E. Alzate R, "Biodegradation of organic solid wastes from market places," *Rev. Colomb. Biotecnol.*, vol. VI, pp. 78–89, 2004.

[8] J. A. Siles, F. Vargas, M. C. Gutiérrez, A. F. Chica, and M. A. Martín, "Integral valorisation of waste orange peel using combustion, biomethanisation and co-composting technologies," *Bioresour. Technol.*, 2016.

[9] E. Paone and D. Komilis, "Strategies for the sustainable management of orange peel waste through anaerobic digestion," *Environ. Manage.*, vol. 212, pp. 462–468, 2018.

[10] P. McKendry, *Costs of Incineration and Non-Incineration Energy from Waste Technologies*, no. March. 2008.

[11] D. A. Zema, A. Fòlino, G. Zappia, P. S. Calabrò, V. Tamburino, and S. M. Zimbone, "Anaerobic digestion of orange peel in a semi-continuous pilot plant: An environmentally sound way of citrus waste management in agro-ecosystems," *Sci. Total Environ.*, vol. 630, pp. 401–408, 2018.

[12] K. J. Valentas, E. Rotstein, and R. P. Singh, *Handbook of food engineering practice*. CRC Press, 1997.

[13] A. Koppar and P. Pullammanappallil, "Anaerobic digestion of peel waste and wastewater for on site energy generation in a citrus processing facility," *Energy*, vol. 60, pp. 62–68, Oct. 2013.

[14] F. Tambone *et al.*, "Assessing amendment and fertilizing properties of digestates from anaerobic digestion through a comparative study with digested sludge and compost," *Chemosphere*, vol. 81, no. 5, pp. 577–583, 2010.