CHEMICAL ENGINEERING TRANSACTIONS

VOL. 91, 2022

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Valerio Cozzani, Bruno Fabiano, Genserik Reniers

ISBN 978-88-95608-89-1; ISSN 2283-9216

DOI: 10.3303/CET2291105

# Optimization of A Route for Collecting Waste Cooking Oil in Bogotá

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Waste cooking oil (WCO) has been an environmental problem in different cities around the world. It has been reported that 1 liter of WCO could contaminate 1,000 liters of water. A possible solution is collection for recycling and integration into different chemical processes, although, due to related logistical aspects, collection in large cities is difficult. In this work, a combinatorial optimization model based on the Vehicle Routing Problem is proposed that seeks to obtain the optimal cost of the WCO in the city of Bogotá produced in restaurants, shopping centers and food services. It was determined that in this city there are 17,008 commercial establishments located in 19 localities that produce 720,000 liters per month. This oil could be collected for the production of biodiesel, for which a representative sample of each locality was taken and a total of 289 collection points were used. For the programming of the model, an adaptation of the VRP Solver application was carried out, which allowed obtaining the optimal collection routes from which a value of US $ 0.22-0.25 was determined as the optimal cost of collection in the city of Bogotá. The results have shown that by applying route optimization, WCO could be collected in Bogotá at a competitive cost compared to virgin palm oil and under the results it is considered a very convenient option for the partial substitution of oil as a raw material in the biodiesel production process.

## 1. Introduction

Waste cooking oil (WCO) is a liquid that originates from the transformation of vegetable oil when it is used at high temperatures (Alptekin et al.,2014), this process changes its organoleptic and physicochemical properties, generating new compounds Worldwide. WCO is the second most polluting liquid in wastewater because concentrations of 1 mg of oil / l in water make it unsuitable for human consumption (Rincon et al.,2014). Recycling the WCO and then using it in the production of biofuels could solve the problems of final disposal of this compound (Ezzati et al.,2018). The reported yield is 1 liter of biodiesel per 1.2 liters of WCO used as raw material (Lopez et al.,2015), (Rodriguez et al.,2018).
Furthermore, due to its high availability and low acquisition costs (Araujo et al.,2019), this compound is an excellent alternative for industrial applications. However, collecting this material from restaurants, shopping malls, food services, and other sources is a major limitation. So it is essential to determine the logistics costs for an accurate economic evaluation (Araujo et al.,2019). Once established the availability of the waste, the next step in the development of the process, aiming to the cost reduction is the optimization of the route (Jiang et al.,2015). Collection and optimization are associated with policies implemented in each country around the world. Different laws of WCO resources are the main issues, such as the penalty and, rewarding mechanisms, and the kitchen waste disposal fee systems (Jiang et al.,2015).
However, these mechanisms have not increased the colleting due to the absence of restaurant recycling facilities and lack of knowledge about of the recycling process. Optimization consists in the search for values of certain variables so that, fulfilling a set of requirements, represented by equations and / or algebraic inequalities,

Paper Received: 15 October 2021; Revised: 11 April 2022; Accepted: 20 April 2022
Please cite this article as: Fernandez C., Bernal A., Leon P., Gelves O., Malagon-Romero D.H., 2022, Optimization of a Route for Collecting Waste Cooking Oil in Bogotá., Chemical Engineering Transactions, 91, 625-630 DOI:10.3303/CET2291105

they provide the best possible value for a function that is used to measure the studied performance (Kampf et al.,2018). Optimization is achieved through mathematical strategies known as methods, which serve as a tool for decision making that maximizes or minimizes an objective function (Belavenutti et al.,2018). Different optimization models can be found in the literature. One of the optimization problems, which has done with routing, is the model of the vehicle routing problem (VRP, vehicle route problem). VRP emerged as an extension of the Travelling Salesman Problem (TSP), in which the restriction of the limited capacity of vehicles is considered, making it necessary to use several vehicles covering different routes to satisfy all customers.
VRP has been applied extensively to transportation and logistics fields to solve the generic problem of satisfying spatially dispersed customer requests using a fleet of vehicles (Bouyahia et al.,2018). VRP models suppose that all vehicles depart from an initial location called depot, visit the customers according to the selected order, and once their capacities are attained they go back to the depot (Bouyahia et al.,2018). VRP has been used since 1959 when was applied to the delivery of gasoline to service stations, setting the mathematical foundation of this problem. VRP is a complex combinatorial optimization problem, which starts from a warehouse and has a fleet of vehicles that must serve a set of customers dispersed in a geographical area, having some specific constraints of the problem (Sepulveda et al.,2014). Constraints could be imposed by market dynamics. VRP is a highly complex mathematical method, because the number of solutions grows exponentially according to the number of nodes, which are represented by clients or warehouses (Dominguez et al. 2018).

## 2. Determination of volume of WCO in Bogotá.

The collection points of the city of Bogotá used in the programming of the model were classified into three groups: restaurants, fast food places and bakeries. The location of each eating place (address, latitude and longitude) was determined using Google Maps and the points were selected from the 19 urban locations in Bogotá. The sample size was determined for 95% of the level of confidence in each locality, taking into account the number of establishments in Bogotá, for this the following equation was used.

$$n = \frac{(k^2 * p * q * N)}{(e^2 * (N-1)) + k^2 * p * q} \quad (1)$$

The questionnaire was made through an interview with producer of WCO for asking: oil cost, amount of oil produced and collection frequency. From the number of places interviewed was taken a sample with a confidence level of 95%, having the same percentage of cases per location. Table 1 shows the information about number of food places interviewed.

*Table 1: Results of the questionnaire sent to food places*

| Number of food places | Number of Interviews | Number of dates of optimization algorithm |
|---|---|---|
| 17008 | 1166 | 289 |

## 3. Model and Mathematical background.

The objective of the model is to minimize the operational costs implicit in the collection, defining the most relevant costs in the process and the distances between the different nodes, in order to design the optimal route that allows to collect the largest amount of WCO at a low cost. In the mathematical formulation, a series of restrictions were taken into account that influence the WCO collection process, which are subject to the proposed model. The mathematical model was developed in accordance with others presented in the consulted literature [9], which were designed from the VRP model. In this model, Z is the WCO collection operating cost. The operational cost was defined as an objective optimization function, according to equation 2.

$$Min\ Z = \sum_{i=1}^{m} \sum_{j=1}^{n} XjiCXj + \sum_{i=1}^{m} \sum_{j=1}^{n} YijCKij \quad (2)$$

*Constrains*

$$\sum_{i=1}^{m} \sum_{j=1}^{n} QKijXji > \sum_{i=1}^{m} \sum_{j=1}^{n} FjXji \quad (3)$$

The first restriction is subject to the sum of the capacity in liters of WCO that the vehicles have that leave from the points of origin i towards the collection points j, which must be greater than the sum of the maximum capacity of the containers in liters of WCO that is collected at the collection points j assigned to transport to the points of origin i. For the programming of the mathematical model, a fleet of vehicles with a capacity of 800 liters was used to optimize the function.

$$\sum_{i=1}^{m} \sum_{j=1}^{n} QKijXji \leq EiXji \qquad (4)$$

The second restriction is subject to the sum of the capacity in liters of WCO of the vehicles that leave the points of origin i towards the collection points j must be less than or equal to the capacity in liters that the points of origin i.

$$\sum_{i=1}^{m} \sum_{j=1}^{n} TPjXji < TMij \qquad (5)$$

The third restriction is subject to the sum of the average collection time for each litter of WCO produced at each collection point j to transport to the plant of origin i must be less than the maximum time available for the journey from the point of origin i up to collection points j for all collection points. In this work, 3 deposits were considered: Biogras S.A.S, Bioils Colombia S.A.S and Biominerals Colombia S.A.S. For the collection process, the average time was assigned according to the amount of WCO collected per point, this time was assigned for the collection operator to receive the WCO, fill out the certificate and load the vehicle. Therefore, a collection time of 15 minutes was assigned for the collection of 30, 50 and 70 liters of WCO and a collection time of 25 minutes for the collection of 90, 120 and 150 liters of WCO.

$$\sum_{i=1}^{m} \sum_{j=1}^{n} TFij \geq TRjXijFj \qquad (6)$$

The fourth restriction the time of collection frequency from the point of origin i to the collection points j must be greater than or equal to the collection time of liters of WCO taking into the capacity of the container delivered to each collection point. According to the collection frequency of the 289 points used, the frequency for programming the model was established in the following three groups and under the following parameters: weekly (between 5 to 7 days), biweekly (10 to 15 days) and monthly (between 20 to 30 days).

## 4. Results

It was determined that in Bogotá there are 17,008 commercial establishments of the type restaurants, fast food places and cafeterias. From the surveys carried out, the amount of oil collected by each surveyed point was determined, which was extrapolated to the quantity offered by locality and for the whole city. In this way it was determined that the amount of oil produced in Bogotá is 720,000 liters / month Each of the surveyed points was associated in a matrix with a geographical position, quantity of oil (liters), cost of oil (US$ 0,13 –US$ 0,2). Figure 1 show the quantity of waste cooking oil produced in each locality in Bogota.

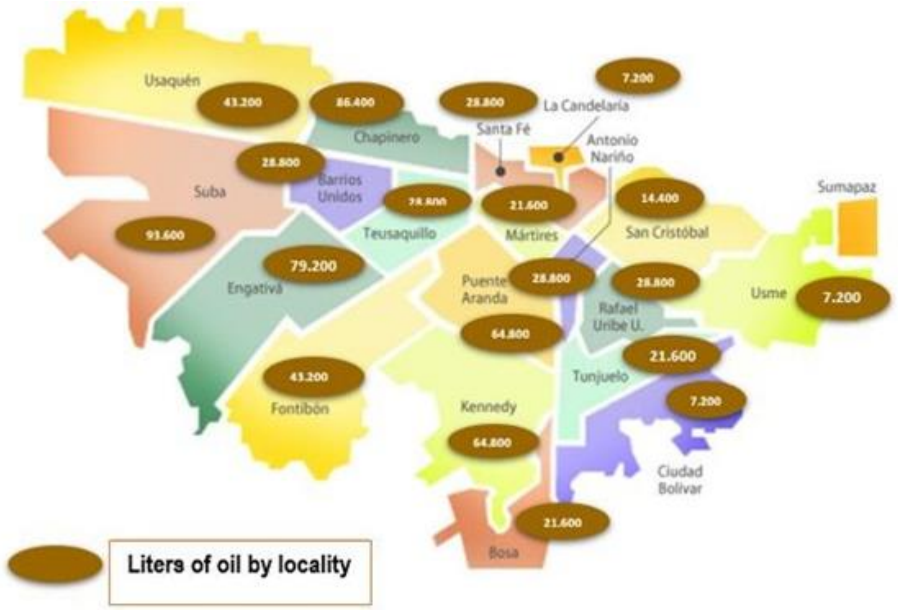


*Figure 1. Distribution of oil collected in Bogotá Source: Authors own creation.*

The total quantity of oil collected would be sufficient for installing a small biodiesel plant (Galeano et al.,2018), because the demand of industrial plant is near to 8,000 tons /month (Zhang,2003). Collecting and recycling WCO contributes to solve three environ- mental problems: waste reduction by product reuse/recovery, reduction of the fossil fuels energy dependence and reduction of pollutants emissions (Ramos et al.,2013). Apart of biodiesel production, the collected oil could be used in the chemical industry to produce soap, detergents, lubricants, paint, grease, among others (Ramos,2013); other possibility is for producing polymers as polyurethane (Moreno et al.,2020). In this way, it is necessary to establish a posterior treatment of filtration, reduction of free fatty acid and reduction of water (Casallas,2018).
The optimization route showed that is a good approximation for solution of collecting wastes. This alternative could identify the source of the waste and trace the best route for transporting it to the collection point. This alternative of calculus had been used in a lot of commercial packages provide tools to solve the CVRP (Capacitated Vehicle Routing Problem) (Lyssgaard et al.,2004). Different advantages of VRP Solver over similar software are: the use of open source tools and free sources of information that are updated periodically, the inclusion of a graphical solution through an interactive map, and free access. It is evidenced that 6 routes were generated and 4125 liters of WCO were collected with a total cost of US $ 820.82 in 81 collection points. Figure 2 shows information about the 6 routes.

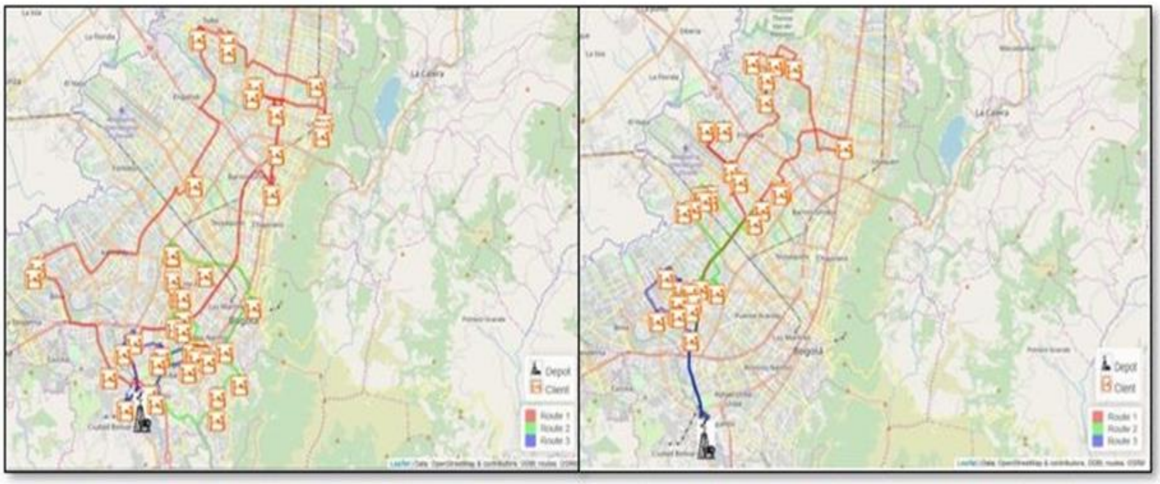


*Figure 2. Weekly route map. Source: VRP Solver application results*

On the other hand, the manager Biolis Colombia S.A.S was programmed for the biweekly collection., it is evident that 6 routes were generated and 4,456 liters of WCO were collected with a total cost of US $ 889.02 in 92 collection points. According to the table 2, it is evidenced that 8 routes were generated and 5203 liters of WCO were collected with a total cost of US $ 1,136.27 in 116 collection points.

*Table 2: Results of the optimization algorithm*

| Parameters | Biogras | Biolis Colombia | Biominerales SAS |
|---|---|---|---|
| Liters of WCO collected | 4125 | 4456 | 5203 |
| Number of routes | 6 | 6 | 8 |
| Distance Travelled Km | 308,1 | 330 | 478,9 |
| Total Cost per Litter of waste oil | US$ 0.22 | US$0.22 | US$0.25 |

## 5. Conclusions

Optimization of the costs associated with producer, collecting and transport of WCO in Bogotá have shown that it is a profitable process. The cost obtained could be competitive with palm oil in biodiesel production. The integration of virgin and collected oil had been evaluated, so technical aspects have been overcome. Additionally, WCO collected could be integrated to other process as soap or polyurethane production.

The integration of heuristics models for optimization allowed an advantage for establishing the optimal point in VRP and TSP. Among the improvements to the model, it is necessary to take into account the existing mobility problems in the city of Bogota, which can generate changes in the results of the applied model, since these problems may imply a change in transportation costs.

## Nomenclature

i = Point of Origin i = 1,2, 3, ….., m
j = Collection points j =1,2, 3, …., n
K = Vehicles = 1,2.
Xji = Liters of OMA produced at each collection point j to transport to point of origin i.
Yij = Distance from the point of origin i to the collection points j (taking into account the distance between the collection points
CXj = Cost of the litter collected at each collection point j.
CKmij = Cost per Km traveled from the point of origin i to the collection points j.
CTKij = Number of vehicles leaving the point of origin i towards the collection points j.
QKij = Capacity of each vehicle K that leaves from the point of origin i towards the collection points j.
Ei = Capacity in liters that the point of origin i can process.
Fj = Capacity of the containers delivered to each of the collection points j.
TMij = Maximum time in working hours for the journey from the point of origin i to the collection points j.
TRj = Collection time according to the capacity of the container delivered to the collection point j.
TPj = Average collection time according to the number of liters to be collected at each collection point.
TFij = Frequency time to carry out the collection at each collection point j.

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