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Design and Construction of a Crushing Machine for Organic Wet Waste of a Restaurant in Mexico

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Abstract

A biogas plant at semi-industrial level was installed to one of the 23 restaurants of University City. The biogas substitutes 6% of the total heat energy consumption of the restaurant. The crushing machine investment represented 80% of the total investment cost of the biogas plant. The efficiency of the anaerobic degradation process depends on an efficient system of crushing. For the operation of the biogas plant needed 3 people, because the crushing of organic waste could take up to 3 hours. 50 kg/day of organic matter are processed to reduce their size from 25 to 3 cm. The crushing time represented around of 90% of work in the plant. In Mexico, the crushing machine must to be imported and the high cost reduces the economic viability of the plant, so we decided to design and construct a prototype of crushing machine with the following characteristics: size reduction by cutting with engine power of 1.5 Hp, speed of 425 rpm, manufacture material of stainless steel 304, 3 rotors and 3 blades coupled to the rotor; and 2 fixed blades in the crushing chamber. This new crushing machine decreased its investment in 95% of the cost of a imported machine. This crushing machine and its components are in the process of obtaining a patent. The optimum operation of the crushing machine reduced the hydraulic residence time in the hydrolysis and methanogenesis process from 30 to 18 days. Therefore also helps to reduce the size of the digester reactor for future designs for organic waste anaerobic treatment of a restaurant.

Keywords: Biogas plant; Organic wet waste; Anaerobic degradation

Introduction

Currently, in Mexico City are produced 13,558 tons per day of Municipal Solid Waste (MSW) by 8,854,600 habitants, [1]. The generation per capita is equivalent to 1.5 kg/habitant per day. Municipal solid wastes are classified into organic and inorganic. The organic wastes are organic garden waste, waste from the preparation and consumption of food. On the other hand, inorganic waste are glass, paper and cardboard, plastics, aluminum and other non- hazardous and recyclable materials of rolled metals.

Food waste need special handling does not pose a risk to the health of society and the environment. Anaerobic Digestion degrades several types of organic solid waste, including food waste. The organic components are degraded by the Anaerobic Digestion process to producing biogas, sludge and other products. The design of a biogas plant is influenced by several factors such as the type of feedstock and operating conditions. Biogas plants fed with organic solid waste have great potential for urban areas in developing countries. Sometimes, the operation of small and medium biogas plants is deficient by the application of poor operating techniques, so the development of functional configurations and competitive in the biogas plant

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design are very important, and also the costs [2]. This work is based on the design and construction of a crushing machine which optimizes the operation of a biogas plant, in a restaurant located at University City.

Case Study

The restaurant is located in Ciudad Universitaria of the National Autonomous University of Mexico. The restaurant is opened six days per week (Monday to Saturday), preparing on average 600 meals per day with monetary incomes around 3,100 dlls per week. The restaurant uses liquefied petroleum gas (LPG) as the main fuel for cooking with a consumption level of 264.5 kg estimated per week, equivalent to 45.8 MJ / kg of prepared food. The demand for LPG for cooking is 12,122 MJ per week [3].

Biogas Plant

The restaurant is installed next to the biogas plant which providing waste of food preparation to feed the anaerobic reactor. The plant is fed 50 kg of organic waste per day. The organic waste is collected from the restaurant; they are selected and crushed in approximately 180 minutes with 3 people labor. Water is then added to adjust the concentration of solids and to reaching the standards of wet digestion **(FIG. 1)**. To perform the following steps of plant operation only needs one person. By means of a pump is fed at the first anaerobic digester (D-1), made stainless steel with volume of 1 m^3, where the early stages of anaerobic digestion are performed. Then the substrate is discharged to the second anaerobic digester (D-2) made high density polyethylene (HDPE) material and with 5m^3 of volume **(FIG. 1.)**.

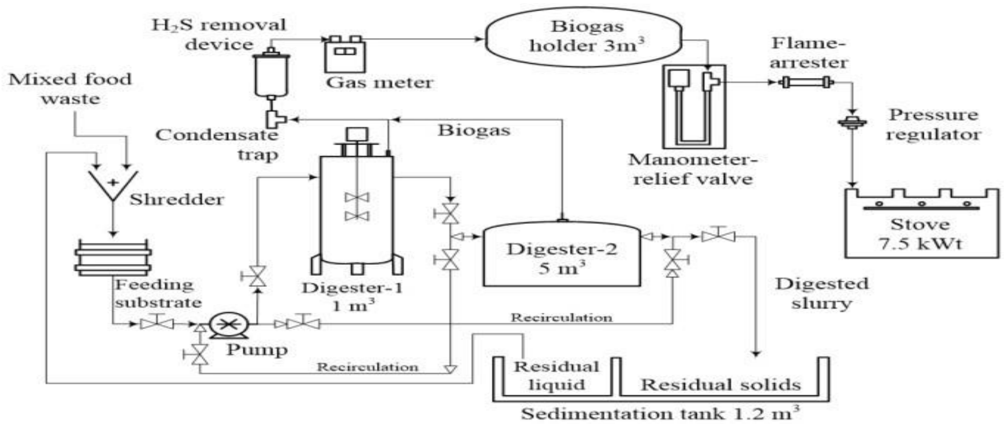


FIG. 1. Overview diagram of the biogas plant [2].

The substrate contained in D-2 is homogenized by recirculating of the effluent by means of a peristaltic pump for 60 minutes. The R-I reactor has a mechanical stirrer and pallets. Once both anaerobic digesters are filled and D-1 is fed by the substrate, D-2 automatically is fed by the effluent of D-1, while a volume of digested sludge exits the settling tank to separate the solid matter from the liquid matter [4].

Problem description

The grinding step is the mechanism that takes more time and human effort of all the process in the biogas plant. This step consists in reducing of waste size from 20 to 1 cm approximately. The crushing action is performed manually with the aid of a knife and then the crushed wastes are discharged to a Insinkerator garbage disposal with a 1HP motor. The operation must be suspended by frequent jamming in the grinding chamber. **FIG. 2** shows the Insinkerator garbage disposal.

FIG. 2. Insinkerator garbage disposal [4].

The particle size affects the biochemical transformation of organic waste into biogas **(FIG. 3)**. The relatively large particles have a longer residence time in the reactor to carry out anaerobic degradation [5]. The arrangement of the microorganisms to the solid feed material and hydrolysis of complex polymeric components constitute the limiting step in biological processes and therefore, it is important and necessary to improve the crushing step. F_o this reason, it was decided to construct a crushing machine to optimize the anaerobic process.

FIG. 3. Sample of organics wastes processed in the biogas plant [4].

One possible scenario to optimize and reduce the time of crushing would be ideal the buying of a Retsch brand crushing machine, manufactured in Germany. It has a value of about 5,287 dlls, but because the value of the crushing machine represents more than 80% of total value of the biogas plant [2], it was decided to design and build a crushing machine.

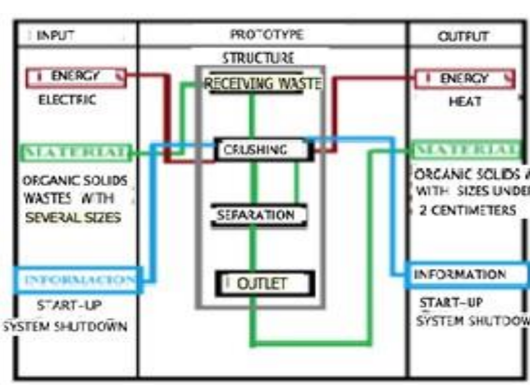
Methodology

The methodology used was the Quality Function Deployment (QFD). It can be defined broadly as a method for developing a design quality aimed at full customer satisfaction. It's also for taking on consumer demand in design goals and elements of quality control to be used in all steps of the production phase. First, it was realized a questionnaire to achieve the specifications of the customer and to know which he requires. **TABLE 1** shows customer requirements converted as goals of design [6].

GOALS OF DESIGN	
Part of the crushing machine	**Specifications**
Structure	Wooden structure adapted to the design of the crushing machine
Rotor	3 Discontinuous stainless steel rotors
Blades	5 stainless steel blades with 45° chamfer
Housings for electric motors	Square-shaped stainless steel housing with welded flanges for attachment
Motor	Motor 1 hp at 1600 rpm
Shaft of the motor	Shaft of 1 inch and 32 centimetres long
Wedge	Square wedge of ¼ * ¾ inch

TABLE 1. Design specifications of the crushing machine [7].

To start the design of the crushing machine were determinate inputs and outputs in terms of energy, materials and information, which can be done with a diagram with service functions and their interrelationships as shown in **FIG. 4**. Finally, once the specifications and functions were established, then we proceeded to perform a conceptual model for prototype of the crushing machine. The crushing machine has a hopper for avoiding direct contact with the grinding chamber. Also, it has 3 stainless steel rotors (type 304) aligned and distributed, so have a wide cutting area; since in its three ends are fixed three blades. The housing for electric motor has a thickness of ¼ inch stainless steel and have two blades coupled allowing cutting material with the blades of the rotors, and having a spacing 1 mm distance between blades when the rotor rotates. The shaft is coupled to a pulley of 16 inches to transmit the engine torque. In **FIG. 5** shows the model of the crushing machine.



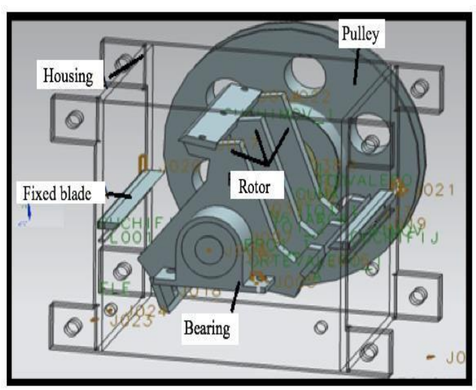


FIG. 4. Service functions and their interrelationships [8]. **FIG. 5.** 3D model of crushing machine

Results

After obtaining the final model, the next step was to make a stress analysis on the critical parts of the crushing machine (shaft, wedges, blades, and rotor) and applying an adequate safety factor to guarantee for normal operation of the crushing machine, and then move to manufacture of crushing machine. The cost required to build the crushed material is shown in **TABLE 2**. In this table, also shows the cost of plates which are essential for manufacturing of crushing machine as well as their measures. **TABLE 3** shows the parts of the crushing machine as screws, pulleys and belts that were purchased.

Material	**Amount**	**Cost (dlls)**
Stainless steel plate T-304 thickness ¼ in	50cm*50cm	48.08
Stainless steel plate T-304 thickness ½ in	20cm*60cm	49.71
Stainless steel bars T-304	35cm	6.96
Stainless steel plate T-304 thickness ¼ in	20cm*20cm	10.00
Stainless steel plate T-304 thickness 1/32in	20cm*60cm	6.00
	Total	120.75

TABLE 2. Materials used for the construction of the crushing machine

Material	**Amount**	**Cost (dlls)**
Steel screw 3/8 Ø	8 x 3 ½ in	1.2
Steel screw 5/16 Ø	4 x 3 ½ in	0.6
Steel screw 3/8 Ø	8 x 1 ½ in	2.0
Steel screw ½ Ø	4 x 3 .00 in	1.6
Aluminum pulley 16 Ø	1	32.2
Aluminum pulley 3 Ø	1	5.5
Bushing	2	16.0
Ball bearing	2	8.0
Rubber band	2	9.0
Hinges	2	0.8
Total	32 pieces	76.9

TABLE 3. Materials that were purchased

Finally, we proceed to carry out the final assembly of all parts. On the one hand, we have the pieces to assemble, as the Housings for electric motors and the fixed blades. On the other hand, purchased parts are screws, bearings, the band, pulleys, motor, table, and wood base. In **FIG. 6** are shown the pieces separately before assembly, these are the housings for motor, pulleys, worktable, bearings, motor, sieve, and input hopper. **TABLE 4** shows the specifications of crushing machine and also, it shows a final image of the crushing machine finished.

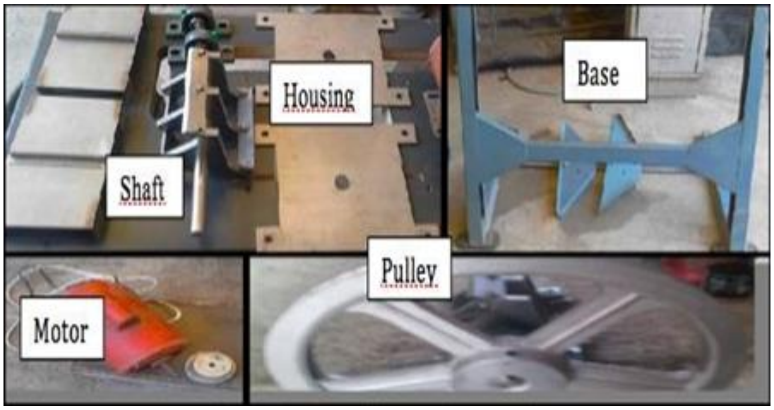
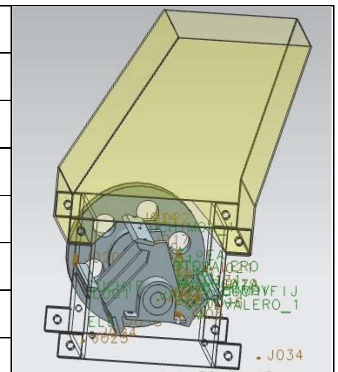


FIG. 6. Pieces of the crushing machine

Goal	Size reduction
Cost	$346 dlls
Areas of application	agriculture, food, plastics
Type of material	soft, semi-hard
Crushing principle	bolt cutter, cutting
Initial granulometry	< 100 x 100 mm
Final granulometry	10 - 35 mm
Velocity (60Hz)	425 rpm
Rotor diameter	129.5 mm
Types of rotor	3 rotors , 3 blades coupled
Material	Stainless steel 304
Motor	Two-phase electric power
Engine power	1.5 Hp
A*H*F	500 x 1500 x 1400 mm



A) Crushing machine

TABLE 4. Specifications of the crushing machine and prototype model

Crushing machine operation

To perform the tests with the crushing machine were collected the food waste about 50 kg per day. Particularly, wastes such as fruit and vegetable peelings of the "Cibarium" restaurant at University City. Then the wastes are prepared to crushing them with the crushing machine. The results were satisfactory since the wastes were crushed without any problems and very quickly. **TABLE 5** shows a summary of the biogas plant operation considering the estimated time and number of people required for each sub-process.

Process with load of 50kg	Without the crushing machine (minutes)	Number of Zorkers	With the crushing machine (minutes)	Number of workers
Collecting of organic matter	5	3	10	1
Sorting waste	20	3	30	1
Crushing action is performed manually with the aid of an knife	150	3	25	1
Crushed wastes are discharged to a Insinkerator garbage disposal	50	1	15	1
Adding enzymes to anaerobic reactor	2	1	2	1
pH measurement	2	1	2	1
Mixing	60	1	60	1
Recirculation system	60	1	60	1
TOTAL	349 minutes=5.81hours		204 minutes=3.4hours	

TABLE 5. Comparison of operation, with and without the crushing machine

Conclusion

The assembling and design of the crushing machine was obtained through the methodology of QFD and it was concluded successfully. From this design, were calculated safety factors and maximum efforts caused by the normal performance of the crushing machine. The calculations were made on the most important parts (rotor, shaft, wedge and blades) to ensure that they will have a good performance. Once the results were satisfactory and that the design is feasible, and then was preceded to construction of the crushing machine. Part of the material used and the cutting of stainless steel plates by water jet were funded with support from the University.

Crushing machine is designed to process a flow of organic matter of 100 kg per hour. Crushing machine is driven by a motor of 1 Hp and its torque is transmitted to the grinding axis by means of two pulleys. The final cost of the crushing machine is the sum of: a) Cost of the stainless steel plate that is 121dlls, b) Parts acquired in the market with a value of 77 dlls, and c) The cutting of stainless steel plates by waterjet with a value of 98 dlls more welding the four corners of the housing. The total value is 346 dlls. If this value is compared with a German similar machine of Retsch brand that has a value of 6,090 euros, can consider that this represents a great economic advantage of the crusher machine of this work versus the machine of the market.

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