SAVONIA

Food Waste Drum Sieve Design

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Bachelor's Thesis

26.03.2015 Technology, Communication and Transport

Bachelor's degree (UAS)

SAVONIA UNIVERSITY OF APPLIED SCIENCES THESIS

Abstract

Field of Study Technology, Communication and Transport			
Degree Programme Degree Programme in Industrial Management			
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Title of Thesis Food Waste Drum Sieve Design			
Date	5.05.2015	Pages/Appendices	49
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Client Organisation/Partners			

Abstract

The food waste pretreatment system is widely used in the EU and USA. Compared with food waste pretreatment system in China, systems in EU and UAS are relatively advanced and impeccable. Based on the characteristics of food wastes in China, in this thesis, some modifications of drum sieve – one important part of the whole system were done in order to improve the efficiency of separation meanwhile achieve the miniaturization of drum sieve.

The biggest difference between the traditional drum sieve and the new one designed in this thesis was that there were no any plates in the drum which made it possible to achieve the miniaturization of the drum sieve. And those plates in the drum were replaced by another machine – bag breaker. Besides the main tasks of this thesis was to design the parameters of each structural size of the drum sieve including the diameter of drum, the length of drum, the thickness of drum, the distribution and the size of the sieve holes on the surface of drum according to the required handling capacity and existing features of food wastes in China.

Apart from the structure designing, the selection of electromotor of drum sieve, proofread of shafts in the drum and in the bag breaker were also needed to be done. And the distance between the shafts and the bag breaking area were also calculated. After that, the manufacture and installation of drum sieve, some relevant inspections and maintains and some notices about daily operation were also told in this thesis

In last part, some introductions to the relevant existing food waste treating methods, the marketing analysis and potential perspective research of our new equipment were also presented.

To sum up, this new type of drum sieve designed in this thesis has the wide range of usage and potential marketing competence, that is to say, this type of drum sieve can be applied into personal business.

Keywords
food waste equipment, design, drum sieve, bag breaker, marketing analysis

CONTENTS

SYMBOLS AND TERMS

a_1 – The center distance between the upper shafts (mm)

a_2 - The center distance between the lower shafts (mm)

D – The diameter of drum sieve (m)

d_1 – The diameter of the small-size sieve holes (mm)

d_2 – The diameter of medium sized sieve hole (mm)

d_3 – The diameter of big sized sieve hole (mm)

d_b – Density of food waste (t/m^3)

F – Filling coefficients (%)

g – Gravity (m/s^2)

G – The weight of food waste in the drum (t)

Kv – Velocity correction coefficients

L – The length of drum (m)

n_1 – Rotating speed with filler (r/min)

n_2 – Rotating speed with filler (r/min)

n_c – Critical rotating speed (rmp) or (r/min)

n_o – Rotating speed of electromotor of drum sieve (r/min)

n_o' – Rotating speed of motor (r/min)

m – Mass of drum sieve (kg)

M_e – External moment of shaft (Nm)

P – Power of motor (kw)

P'_0 – The Rated power of motor of bag breaker (kw)

Q_1- Maximum mass flow rate (t/h)

Q_2 – Mass flow rate after screening (t/h)

Q_a – Volume flow rate of drum sieve (m^3/h)

Q_m – Handling mass of drum (mass flow) (t/h)

Q_n – Volume flow (m^3/h)

R_t – Total recycling rate (%)

R_u – Recycling rate (%)

S – The area between two shafts in beg breaker (m^2)

S_1 – The area of upper layer of bag breaker (m^2)

S_2 - The area of lower layer of bag breaker (m^2)

T- The time of staying in the drum (food waste) (s)

t_1 - Time of circumferential motion along the drum screener (s)

t_2 – Time of finishing a total parabolic motion (s)

V – Rotating linear velocity of drum (m/s)

$\bar{v}$ - Axial motion velocity of food waste (m/s)

W_t - Section modulus in torsion (m3)

α - The inclination angle of drum sieve (°)

Θ – The leaving angle of element (°)

φ_1 – The ratio of rotating speed n1 to n2

φ_2 – The ratio of rotating speed n2 to n1

δ - The thickness of drum sieve (m)

COD – Chemical oxygen demand

BOD – Biochemical oxygen demand

1 INTRODUCTION

1.1 Brief introduction to food wastes

The urban wastes include food wastes, general garbage, and yard wastes. However, in all sorts of urban wastes, food wastes account for the biggest part. The type of urban waste has some “embarrassing characteristics”. They are:

1) The content of organics is high.
2) The shapes of food wastes are totally complex.
3) The geometry sizes are different.

These special characteristics will directly lead to the chaotic group classifications and high water-content in the food wastes. In the other words, the essence of these characteristics is that it is hard to make sorting and classifying efficiency and purity reach a satisfying level. Nowadays, the methods of recycling treatment of food wastes can be divided into two groups:

1) Incineration: It is well known that incineration need to be provided for large amount of fuels which can extremely increase its recycling cost. Secondly, most dusts and chemistry particles produced in the process of recycling treatment seems to pollute atmosphere and environment. Besides, transporting huge number of daily food wastes and fuels will also need many investments including capital investments and labor investments. However, until now this is still no totally completive and high-efficient treating system to solve this problem. Although in the treating process, population will be inevitably created and huge amount of capital investments is also an indispensable part, this method could not be replaced and will be used for next long periods.

2) Landfill: There is no doubt that landfill is much better than incineration. But it also has some limitations. For example, much more areas of land are required. Especially, it will be a big problem for some countries that have no more land resources. Furthermore landfill has long period of degradation. If food waste cannot be buried deeply, bad smell will be created day by day.

These two sorts of methods of food wastes treatment are good solutions to present troubles. Due to the high speed of urbanization and increase of urban population, the sophisticated equipment and processes are urgently needed to proceed increasing large amount of daily food wastes.

1.2 The background and meaning of recycling treatment of food wastes

The present situation of food wastes treatment has led many people to worry that whether our city will become the "food waste city" in the future. Apart from bad smell produced by the stacking food waste, in the process of degradation of food wastes, many contaminants not only have an adverse influence to nearby surface water but also make the ground water deep seriously deteriorate. Some contaminants with the low density such as plastics and waste paper will blow into the air and result in the environmental contamination. Moreover, the ordinary method of burying underground will produce biogas and become the "sporadic bomb". Some harmful and poisonous particles without any treatment in the food wastes easily come into the soil and become the potential threats. (Li Bing, 2011, 22)

Hence, there is an urgent need for us to build the sophisticated system of recycling treatment of urban food wastes which can dramatically reduce the threats to the human being's health and life environmental deterioration. With a good and reasonable food wastes treatment system, our living environment and human being's health not can be modified and be enhanced meanwhile the beautiful and livable city will be gradually built up. (Meng Baofeng, 2009, 55)

2 SYSTEM DESCRIPTION

2.1 The traditional pretreatment and conservation system of food-waste

2.1.1 Brief introduction to system

This system is mainly used for the centralization of waste-food processing system, as the first-end pre-treatment of resources utilization of the processing system can primarily be divided into a material feeding system, a sorting and a purifying system, a solid-liquid separation system, a smashing system and deodorizing system. Through the whole system, except the sorting and purifying system that is involved in some manual interventions, other systems are all easily controlled by automatic operation.

2.1.2 Description of entire system

a) Feed-in conveying system

Food-waste is first transported into a disposal plant by garbage trucks. After weighing through an electronic weighing device, it is poured into conveyors in which the bags loading the food-waste are broken meanwhile effluent food-waste are delivered to receiving hopper and simultaneously drained and dehydrated before being transported into the sorting and purifying machine. (Zheng Jinyang, 2010, 23)

The functions of this system include temporarily collecting and storing of food-waste which is transported by garbage trucks, breaking packaging bags of food-waste, draining and transferring dirty water. Considering transported food-waste contains about 70% of free water, if this high oil sewage were directly transmitted into the next sorting and purifying system, it would cause difficulties in the sorting and purifying system. So there is no doubt that putting into the material feed-in system to drain 80% of free waste water is extremely important for after-treating systems. In addition to the waste water, this food-waste also includes the large amount of plastic packaging bags, and it is hard to sort and collect after they are delivered into sorting and purifying system. Hence these bags must be broken and smashed during the period of downloading in order to make sure that food-waste in them can be successfully dumped out. (Zheng Jinyang, 2010, 23)

b) Sorting and purifying system

The functions of this system focus on sorting and purifying garbage which has been leached and drained when passing by the previous working process. This procedure can be divided into two stages – first-class sorting and second-class sorting. For the first-class sorting, it is used to sort some substances with light weight such as plastic bags, plastic bottles and so on out from larger amount of food-waste. All these substances are transported into a station where some manual interventions are needed after being sprayed and washed by the hot water. Meanwhile some heavy materials for example bones, china bowls and so on are conveyed into the second-class working station where the heavy materials are further sorted and classified according to the different sizes and weights to be collected and sorted out as well after being sprayed and washed by the hot water. Finally after classification, the bigger wastes (including some biomasses) are transferred to the manual working station to sort further and some small material wastes come into hold-up vessels to go on to the solid-liquid separation. (Zheng Jinyang, 2010, 24)

c) Solid-liquid separation system

In order to preferably fit in the latter working treatments at same time to efficiently separate the oil out from food-wastes, solid-liquid separation can be necessarily proceeded on. Through this system, the goals of treatment can be fulfilled so that the ratio of solid-liquid food-waste is 1:10 and only 20 % of contents of solid waste-food is free-state water. This part of solid food-waste directly comes into smashing system to be shattered. Then the materials with liquid state are delivered to oil and water separation system. (Zheng Jinyang, 2010, P24)

d) Oil and water separation system

The function of this system is to get all sorts of water (including free-state water in food-waste, spraying water and washing water) together into a water pool. After being precipitated, supernatant liquid can be gained from the top layer of water pool and is heated to 40-80 ^{o}C by using mechanical method in order to further complete oil-water separation. Separated oil comes into the follow-up purifying process. However, separated water is either directly transported into biogas pool for biochemical treatment or through waste water treatment system to become reused water of the whole system. (Zheng Jinyang, 2010, 24)

e) Smashing system

Before coming into the system of recycling utilization, squeezed materials should be smashed and taken into smashed garbage. From experimental experiences, it has been known that in the process of smashing, grease in the garbage will emulsify according to the different degree of smashing. Concerning this point, with the purpose to smash big biological wastes to facilitate the coming biochemical treatment, the smashing system should be placed behind the solid-liquid separation system. (Zheng Jinyang, 2010, 25)

f) Spraying and Washing

The hot water heated to the temperature with 40-80 ^{o}C is used to wash, clean and remove grease and salt on the surface of dishes and bowls to improve oil yield which is convenient for the follow-up biochemical handling process where material will be transported and after-washing waste water will be discharged into sump. (Zheng Jinyang, 2010, 25)

g) Deodorizing system

Pretreatment plant is sprayed with natural plant extracts, to further reduce the spread of odor. (Zheng Jinyang, 2010, 25)

2.2 New type of pretreatment system

2.2.1 The requirements of design

The requirements mainly focus on specification of make-ups and components of Chinese food-wastes and provide a highly efficient, fast and stable method for the separation of the major components of food waste. This method shortens the processing chain of food-wastes which is easy for engineering application of harmless disposal to simultaneously reduce contamination and occupation of environmental resources in order to achieve economic, social and environmental comprehensive benefits.

2.2.2 The entire scheme

Through the material feed-in hopper, food wastes are directly downloaded into a wash bucket where these food wastes are automatically broken up and washed. When after-washed food wastes coming into a screening drum, liquid slurry materials and solid wastes with larger size start being separated in it. Separated solid wastes with the larger size will be transferred into incinerators or landfills to further harmlessly incinerate or landfill. Meanwhile the slurry liquid material will come into the extrusion cylinder which includes hydrolyzed and refined organic materials and aqueous phase liquid materials. This system is shown in Figure 2.1 below.

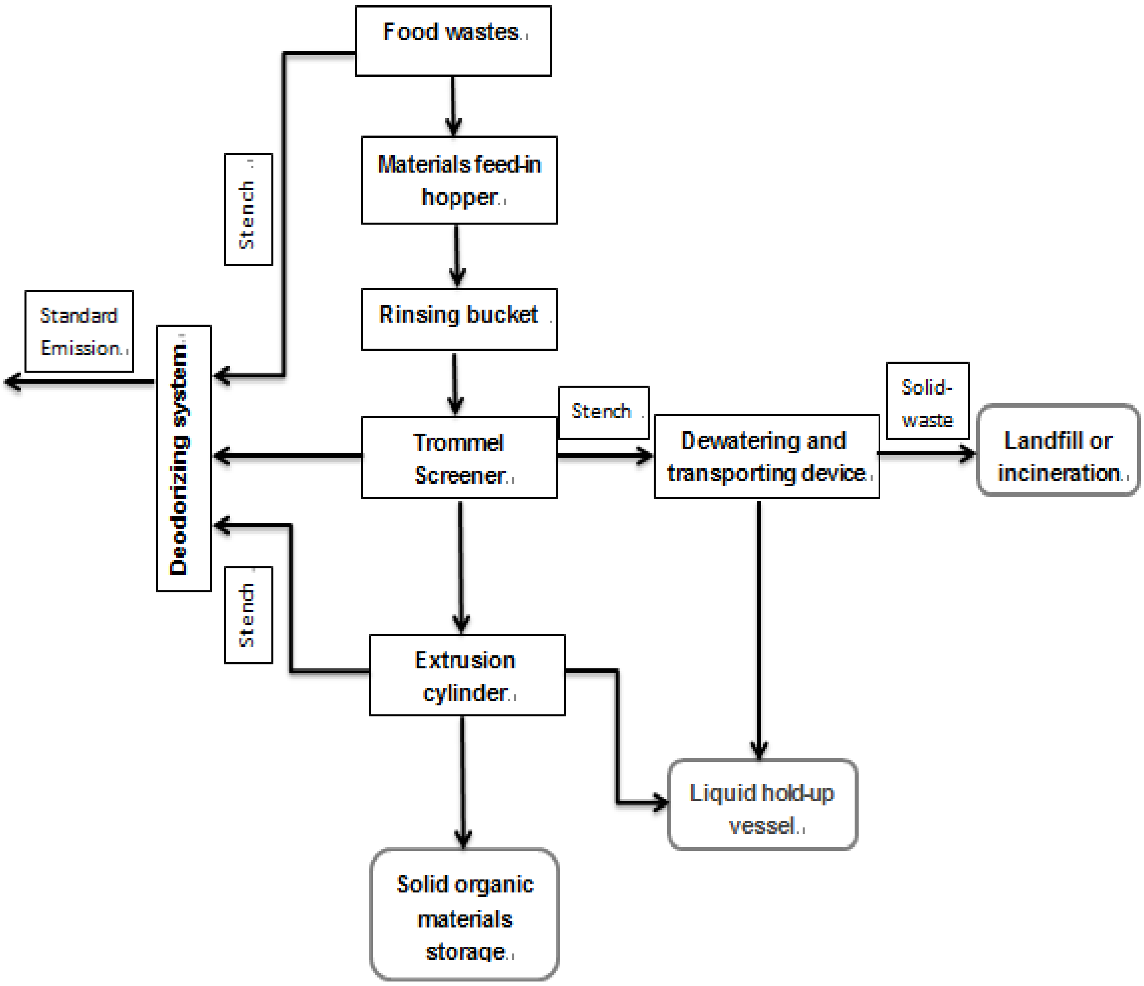

Figure 2.1 Food waste pre-treatment processing flow chart (Yaoxuan Zhu, 2015)

2.2.3 Detailed steps of the whole designing scheme

Food wastes are transported to processing systems by the specific food-wastes trucks and through a material feed-in hopper and are directly thrown into rinsing bucket.

1) Spraying and washing step

The rinsing bucket is matched with a variable- frequency electromotor. Its rotating speed can be adjusted as needed to about 40 revolutions per minute. In the bucket, eight triangle teeth are assembled and utilized to rotate food wastes with contents of 80 % water which is in favor of sub-sequent treatments and solving the problem that food wastes usually block small holes and subtle places of a device.

2) Automatic sorting and purifying step

Rinsed materials are discharged into the drum sieve. After rinsing treatment, viscosity and liquidity have been improved a lot to easily proceed on material transportation and separation. In the drum screener, due to the rotating motion of the drum, food wastes can be divided into different grades according to the particle size. When coming into the drum, materials are affected by rotary motion of drum to do helical movement. So the particle size smaller than the screening hole will be screened out of the drum and materials left in the drum have the larger size than that of the screening hole.

3) Solid-liquid separation step

When food wastes have been separated and entered the extrusion cylinder, the action of extrusion cylinder to block oil tank is driven to block piston and the discharging port of the extrusion cylinder. Through the first feed inlet, food wastes enter the extrusion cylinder where the squeezing oil cylinder starts moving and driving squeezing piston and the cover of squeezing pipe to achieve the movement of the oil cylinder in order to squeeze liquid in food wastes out by interaction between the oil cylinder tank and the extrusion cylinder. At this time the blocking oil tank retracts, extrusion cylinder continuously moves forward and the material-pushing cylinder acts to push the squeezing oil cylinder to the discharging chute. Dried solid food wastes in it are also pushed into smashing device to the next step of processing. Through holes on the extrusion cylinder extruded liquid flows into the discharging tank at the bottom of extrusion cylinder. Then by the drainage pipe under the discharging tank, extruded liquid is discharged into the reservoir tank. After further oil-water separation by the separator, extruded liquid will become as separated oil used as industrial diesel and as waste water discharged into sewage.

4) Dewatering step

In this step, the third feed inlet is closed and the heating device continues to heat with the purpose of drying for 5 to 10 hours. In the process of drying, steam created through intake-tube from air outlet enters the deodorizing device and is prepared for treatment. After completion of the drying, second discharge port in the side of the fermentation tank is opened and the stirring shaft is started. Due to the diversion of the agitator blades on the stirring shaft, it makes materials in fermentation tank become into particulate pretreated material and be discharged out.

5) Deodorizing step

After entering the deodorizing device, odor is shunted to the ionization tube where odor molecules are ionized to rupture their chemical bonds that directly decompose them into elemental atomic including a single proton or harmless gas molecules constituted by a single atom. In addition to the odorous gas discharged out through air outlet which is in the side wall of the condensation chamber, in the process of gas ionization, axial fan is used for cooling the power supply module and the whole ionization process. After cooling, gas is discharged out through air outlet in the bottom of the deodorizing device and the water created in the condensation is discharged to municipal sewage treatment systems through condensation outlet.

2.2.4 Advantages and disadvantages

The big difference between this new method to the pre-treatment of food waste and existing technology is that this invention has some advantages such as the easy and simple operation, short processing circle and so on. Compared with this new invention, the measures of traditional food waste pre-treatment are mainly made up by these processes, for example solid-liquid separation, smashing, sorting and screening, slurring, oil-water separation and so on, which not only have long processing chain but have high requirement of equipment with reason of characteristics of high viscosity of food waste that usually leads to blocking of facilities, low processing capacity and even stoppage of equipment. All of these affect seriously the normal working of the system. The method described by this invention can achieve the pre-treatment of food waste by only three steps which are rinsing and washing, comprehensive sorting and classifying and solid-liquid separation respectively. By this convenient and swift way, it is easy to fulfill the high-efficient, swift and stable decomposition of each main composition of food wastes, the change of previous complicated way of traditional pre-treatment of food wastes and short processing cycle of waste food to provide more conveniences to engineering application of harmless treatment of food waste. The first step of this scheme is to proceed on processing of washing and rinsing with the purpose to improving conversion rate of oil by partly precipitating oil in the animals and plants. Meanwhile the organic materials are hydrolyzed and refined to achieve the best anaerobic fermentation conditions in the next treatment process which can prominently improve the conversion rate of bioenergy. This invention also includes dewatering and transporting device in order to further reduce the moisture of discharged solid wastes and recycle and utilize aqueous phase liquid that improve recycling utilization rate of material and make them more environmentally friendly. Besides, organic materials and liquid materials are reserved separately. These two different materials will have deep treatments in the different ways where oil is made into bio-diesel. Water can be used for anaerobic fermentation to produce biogas. After fermentation treatment, solid organic materials can be made into inoculants and chemical fertilizers. In order to control the secondary pollution created by industrial waste gas that happens in the process of treatment of food waste, setting up collection of industrial waste gap and treatment system is necessary to intensively collect odor created by the system and send them to deodorizing system where full-fledged gas will be produced and released.(Dong Zhixing, 2011, 89)

The described pre-treatment of the food waste, by the pretreatment process, achieves the separation of the major components of food waste to improve the effect of food waste harmless treatment, the conversion rate of food waste biomass energy, economic effectiveness on food waste recycling products and finally to reduce food waste processing costs. These pretreatment methods described in the scene can be found to overcome all domestic gaps and defects of food waste pretreatment technologies. Because of particularity of Chinese food waste components and composition, this method integrates with the new food waste pretreatment process to solve the existing problems including long processing chain, equipment, high cost of equipment, low reliability, poor stability and other technical defects. At the same time it reduces environmental resources occupancy and pollution to achieve economic, social and environmental comprehensive benefits.

The whole system of food wastes pre-treatment can be made up with different machines and equipment. Generally these machines can be reasonably integrated and combined with each other in order to achieve the whole pre-treatment system. The more details can be found from below in Figure 2.2.

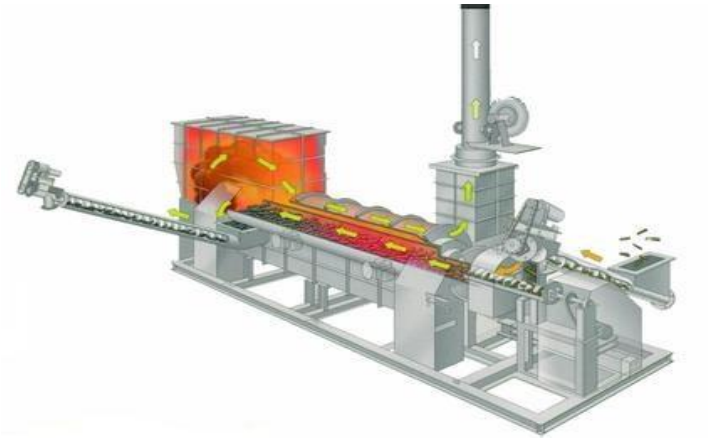

Figure 2.2 The whole system of food waste treatment (Xinhuashe,2015.)

2.2.5 The classification of equipment

Based on those systems mentioned earlier, in order to achieve the assumption about these systems, some devices should be assembled and integrated together. And there are materials feed-in device, a rinsing device, a drum sieve, an extrusion cylinder, a water-removal and drying device and ionized deodorant device respectively.

With the reason that, to some extent, the existing design and manufacture of these machines (except drum sieve) is comprehensive and has reached a related high level, there is no too much room for us to do some modifications of these machines. Hence in this thesis, the purpose is not to re-design these machines but try to do some modifications and innovations about the drum sieve and its accessorized machine that can be matched with it.

As the main classification equipment in the whole process of collecting and classifying food wastes, the drum sieve that firstly is used in the whole treating process is undoubtedly regarded as an important and dispensable part in a food waste treatment machine. The drum sieve is a sort of classification equipment in which with help of the rotating motion, the food wastes with different sizes can be collected and classified into different groups. Besides the drum sieve is assembled with the certain inclination angle that can easily make materials (food wastes) in the drum do spiral movements while rotating. Due to many sieve holes with different sizes on the surface of drum sieve, during the period of rotating, the materials whose size is smaller than the sieve hole on the drum will be separated out of the drum through these sieve holes meanwhile other materials with the size bigger the sizes of sieve holes will collected in the drum.

2.3 The theory of scheme

The theory of traditional drum sieve: the electromotor and reducer make gears rotate. Through a chain, two of four friction wheels are connected with each other. By utilizing tools installed in the drum sieve and sieve, the rotation of drum sieve can break the bag of food wastes and classify food wastes based on the size differences between the sieve holes on the drum and food wastes. (Cai Yunlang, 2010, P69)

However, this kind of traditional drum sieve is a little bit different with the new drum sieve which will be re-designed in this thesis. The difference is that there are no any tools designed for breaking bags in the new drum. The advantage of this is to dramatically increase the rotating speed of the drum sieve and to ensure that when decreasing the length of the drum sieve, its handling capacity will simultaneously not be reduced. In this situation, not only the drum sieve will be designed but the new sole bag breaker will also be made.

The Bag breaker: The bag breaker is a type of mechanical bag breaking equipment in which bagged powder materials or bagged particle materials are disposed. In this scheme, the bag breaker specially designed for breaking the plastic bags of urban food wastes is used. Its theory is that by installing annular breaking-bag tools on the two parallel shafts, the rotation of shafts provided power by electromotor makes annular breaking-bag tools rotate in the drum sieve to achieve bags breaking. (Cai Yunlang, 2010, P69)

3 THE DETAILED DESIGN OF TROMMEL

Due to the lack of research on this type of machines in China, most parameters of detailed design come from daily experiences. By analyzing characteristics of movement in screening and sorting processes, following calculation can be used for confirming its parameters.

3.1 Motion analysis of food waste in the drum

All motion analyses of food waste in the drum can be divided into two main types of motion analyses that are motion analysis of element P in the plane xoy and motion analysis of Element P along z-axis.

3.1.1 The motion and analysis of element P in the plane

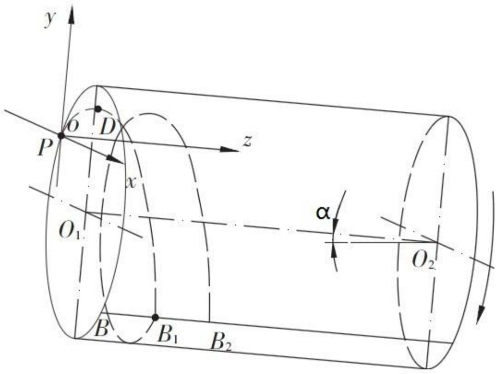

Figure 3.1 The analysis of motion of food waste in the drum (3D) (Zhang Zhen, 2013, P33)

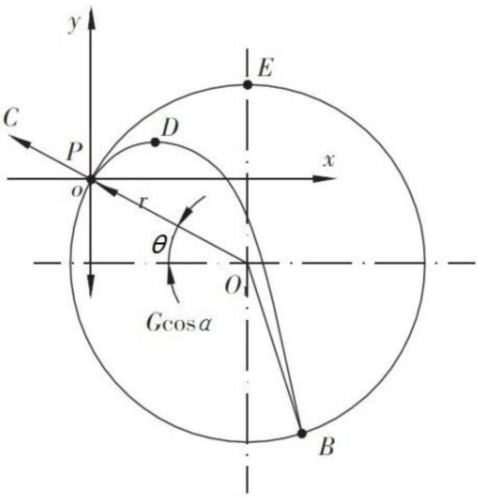

Figure 3.2 The movement locus of food waste in xoy plane (2D) (Cai Yunlang , 2002, 38)

The movement of element P in xoy-plane can be shown in Figure 3.1 or Figure 3.2. Its movement is divided into two parts: circular motion from B to O and parabolic motion from O to D then to the B_1 point. The following is the detailed motion formulas:

The formula of circular motion:

$$\begin{cases} x = r\cos\theta + r\cos\omega t \\ y = -r\sin\theta + r\sin\omega t \end{cases} \tag{1}$$

The formula of parabolic motion:

$$\begin{cases} x = vt\sin\theta \\ y = vt\cos\theta - \frac{1}{2}gt^2 \end{cases} \tag{2}$$

In the formulas: r - The distance of element P to axial line of screener in xoy plane,

t - The moving time of element P,

v - Linear velocity of element P in xoy plane when leaving

ω - Angular velocity of trommel

θ - Leaving angle

g- Gravity constant

From the motion formula of element P, the formula of its movement locus can be gained. They are:

The formula of locus of circular motion:

$$(x - r\cos\theta)^2 + (y + r\sin\theta)^2 = r^2 \quad 0 < r \le R \tag{3}$$

The formula of locus of parabolic motion:

$$y = x\cot\theta - \frac{x^2}{2r\sin^3\theta} \qquad 0 < r \le R \tag{4}$$

In formulas: R – Radius of drum

According to Formula 3 and Formula 4, it is easily worked out that intersection points of two curves of any circle and parabolic line are respectively the original O (0, 0) and B (4rsin2θcosθ, -4rsinθcos2θ). When r = R (R is the radius of screening drum, in other word, food waste is located inside the wall of the screening drum and intersection points of two curves are respectively (0, 0) and (4Rsin2θcosθ, -4Rsinθcos2θ). In order to get the higher sorting and screening efficiency, we must make materials in the drum to have a large turning so that materials in the drum can gain the maximum drop in the parabolic motion. That is to require ($y_D - y_B$) in Figure3.2 to have a maximum value. In Formula 4, taking the derivative of x to get:

$$\frac{dy}{dx} = \cot\theta - \frac{x}{r\sin^3\theta} \qquad (5)$$

If $\frac{dy}{dx} = 0$, so we can find:

$$x_D = r\sin^2\theta\cos\theta \qquad (6)$$

Input x_D into the Formula 4:

$$y_D = \frac{1}{2} r\sin\theta\cos^2\theta \qquad (7)$$

When $y_B = -4r\sin\theta\cos^2\theta$:

$$(y_D - y_B) = \frac{1}{2} r\sin\theta\cos^2\theta + 4r\sin\theta\cos^2\theta \qquad (8)$$

Supposed $\frac{d(y_D - y_B)}{d\theta} = 0$, we can get:

$$\cot\theta = \sqrt{2}, \quad \theta = 35.264° \qquad (9)$$

From above calculations, it can be known that when θ = 35.264°, $(y_D - y_B)$ can have a maximum value and materials in the drum also reach the thorough turning.

3.1.2 The calculation of size of drum

As shown in Figures above, as the rotating speed of drum increases, the drop point of parabolic motion of food waste starts becoming higher and higher. When it reaches certain value, the centrifugal force of food waste is larger than its gravity. At this time, waste food proceeds on centrifugal motion and surpasses the vertex and never falls down. As described above, the critical condition of motions of gravity and centrifugal force is (Cai Yunlang, 2002, P45)

$$P \geq G \qquad (10)$$

In which: P – Centrifugal force (kN)

G – Gravity of food waste (kN)

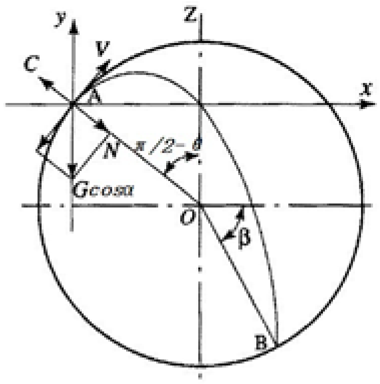

Figure 3.3 The analysis of motion of food waste in drum (Plane)(Yaoxuan Zhu,2015)

Supposed that the linear velocity of drum is V, when food waste rises to point A:

$$P = N \text{ or } mv^2/R = G\sin\theta\cos\alpha \qquad (11)$$

In formula: N – The normal component force of gravity G (kN)

R - The radius of drum (m)

α- The inclination angle of drum sieve (°)

θ – The leaving angle of element (°)

Putting G = mg into Formula 11:

$$V^2 = Rg\sin\theta\cos\alpha \qquad (12)$$

Because of $v = \pi R n_1 / 30$, putting V into equation (12):

$$n_1 = \frac{30\sqrt{g}}{\pi\sqrt{R}} \bullet \sqrt{\cos\alpha} \bullet \sqrt{\sin\theta} \qquad (13)$$

Where n_1 – working the rotating speed of the food waste drum screener, g = 9.81m/s^2 $\pi \approx \sqrt{g}$:

$$n_1 = \frac{30}{\sqrt{R}} \bullet \sqrt{\cos\alpha \sin\theta} \quad (r/\min) \tag{14}$$

As described above, when drum approaches critical condition of rotating speeds n_c, food waste rises to vertex Z and never falls down. Hence,

$$P = G\cos\alpha,\ \theta = 90°,\ \sin\theta = 1,\ D = 2R,$$

And we can get:

$$n_c = \frac{30}{\sqrt{R}} \bullet \sqrt{\cos\alpha} = \frac{42.3}{\sqrt{D}}\sqrt{\cos\alpha} = \frac{42.3}{\sqrt{D}}\sqrt{\cos\alpha} \quad (r/\min) \tag{15}$$

Where: D – The diameter of drum

α- The inclination angle of drum sieve

From Formula 10, it is known that n_c and D have inversely proportional relationship. Hence, we can deduce the state of centrifugal motion of food waste in the body of the drum that is a process in which the rotating speed gradually decreases from outer layer to inner layer. In order words, if the working state of food waste drum can be divided into some layers, then food wastes located at the outermost layer of the cylinder are in the most favourable conditions of work, The rest of food wastes located at the inner layer are under the adverse working condition. If we want all food wastes to be under the better state of sorting and screening, we can make a hypothesis that all food wastes can be gathered together into one certain layer called compressing layer when designing a food waste drum screener. Then only by ensuring that this compressing layer is under the best working state, it can be guaranteed that all food wastes are under the ideal sorting and screening state. According to this assumption, calculating formula of working rotating speed under the favourable state of sorting and screening can be theoretically deduced.

$$n_2 = \frac{37.2}{\sqrt{D}} \bullet \sqrt{\cos\alpha} \quad (r/\min) \tag{16}$$

Where n_2 is the rotating speed of "compressing layer" of drum under the ideal working state

In order to facilitate the expression, universally, ratio ψ of real rotating speed or working rotating speed and critical conditional rotating speed is used to express:

$$\varphi_1 = \frac{n_1}{n_c} \times 100\% = \frac{\frac{32\sqrt{\cos\alpha}}{\sqrt{D}}}{\frac{42.3\sqrt{\cos\alpha}}{\sqrt{D}}} \times 100\% = 76\% \qquad (17)$$

$$\varphi_2 = \frac{n_2}{n_c} \times 100\% = \frac{\frac{37.2\sqrt{\cos\alpha}}{\sqrt{D}}}{\frac{42.3\sqrt{\cos\alpha}}{\sqrt{D}}} \times 100\% = 88\% \qquad (18)$$

So, the most ideally favourable working rotating speed is n:

$$n = (0.76 – 0.88)\ n_c$$

Some devices used to modify the whole performance of the drum are some longitudinal plates which are applied to the inlet of the drum body. Without this modification device, most ideally favourable working rotating speed is regarded as the maximum value of critical rotating speed.

The prerequisite that food wastes cannot slide in the body of the drum is that tangential force of food wastes' gravity should be equivalent to the friction force. Under certain circumstances, the slide of food waste occurs in the drum body (moisture content of food waste more than 50%). That is the moment when tangential force of food wastes is greater than friction force, although working rotating speed of the drum is maintained in the range of $n > n_c$ or $n >> n_c$, food waste is still in the process of sliding down. Therefore, waste cannot do centrifugal motion which leads to the high moisture content of required processing food waste. In this situation, trash can move under supercritical rotating speed. The movement of this kind of supercritical rotating speed can be an appropriate increase for drum processing power. However, it must be determined by the test based on the actual situation. (Sheng Jinlang, 2013, 89）

Under the ordinary situation, without switch-plates in the body of the drum, the working rotating speed is 0.8 times of rotating speed limit. If there are switch-plates in it, the working rotating speed will be 0.5 times of rotating speed limit. （Sheng Jinlang, 2013, 93）

Rotating speed:
- 1. Switch-plates: 0.5 n_c
- 2. No switch-plates: 0.8 n_c

3.1.3 The motion and analysis of Element P along z-axis

Assuming that the element P does not occur to slide axially in the drum body, the motion of element P along z axis is intermittent. As shown Figure 3.1 above, it is known that element B completes every cycle at same time s creates a displacement BB_1 along the direction of z axis. Therefore, it is easier to work out the moving distance and completive time required for one cycle. And then the average speed of element P along the z axis will be calculated. (Yang Xuequan, 2002, 99)

(1) For element P, the time of finishing each cycle includes the time of circumferential motion along the drum screener t_1 and time of parabolic motion t_2. Assuming that there is no slippage between element P and the drum body, its time of circumferential motion along the drum I can be calculated out by the angle $\angle oO_1B$ and rotating speed. From coordinate point B, we can find (Sheng Jinlang, 2013, 70):

$$\angle oO_1B = 4\theta$$

Θ – Leaving angle of element in drum sieve

Thus:

$$t_1 = \frac{2\theta}{3n} = \frac{2\times 35.3}{3\times\left(\frac{29.7}{60}\times 360\right)} \approx 0.133\ s \quad (19)$$

In formula: θ – Leaving angle of element in drum sieve (^{o})

n - Rotating speed of drum sieve (r/min)

From the parabolic function and coordinate of B point, the time of parabolic motion of element P can be got:

Input θ = 35.3° and R = 0.9 m into Formula 7:

$$y_D = \frac{1}{2} \times 0.9 \sin 35.3 \cos 35.3 \cos 35.3 = 0.173\, m$$

$$y_B = -4R \sin\theta \cos\theta \cos\theta = -4 \times 0.9 \times \sin 35.3 \times \cos 35.5^2 = -1.38\, m$$

Input θ = 35.3^o and R = 0.9 m into Formula 8

$$|y_D - y_B| = 0.172 + 1.38 = 1.55\, m$$

$$t_a = \sqrt{\frac{2y_D}{\cos 4^0 \times g}} = \sqrt{\frac{2\times 0.173}{\cos 4^o \times 9.81}} = 0.1880\, s \quad (20)$$

In the formula: t_a – Time when element P moves from point O to point D

g - Gravitational constant

$$t_b = \sqrt{\frac{|y_D - y_B| \times 2}{\cos 4^o \times g}} = \sqrt{\frac{1.55\times 2}{\cos 4^o \times 9.81}} = 0.5634\, s \quad (21)$$

In the formula: t_b – Time when element P moves from point D to point B

g - Gravitational constant

$$t_2 = t_a + t_b = 0.1880\text{ s} + 0.5634\text{ s} = 0.75\text{ s} \quad (22)$$

In the formula: t_2 – Time of finishing a total parabolic motion (s)

Where n is rotating speed of the drum sieve, so the time of finishing each cycle of element P:

$$\text{t} = t_1 + t_2 = 0.133 + 0.75 = 0.883\, s \quad (23)$$

In formula: t_1 - The time of circumferential motion

t_2 – The time of parabolic motion

After completing each cycle, for element P, the moving distance along z axis of drum is the length of BB_1. By the moving equation and moving time, the displacement of finishing each cycle Δl (Sheng Jinlang, 2013, 70):

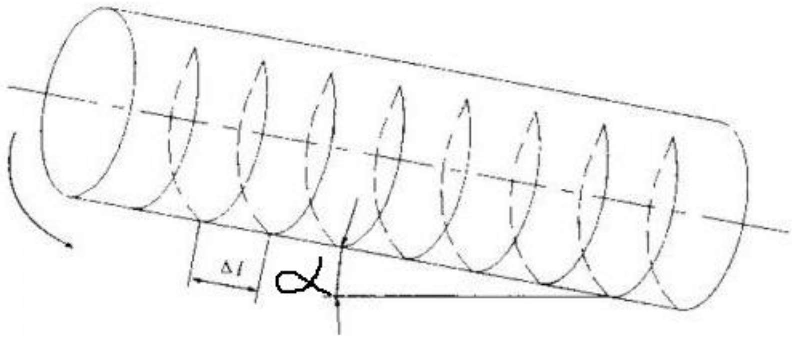

Figure 3.5 The movement locus of materials in the drum sieve (Yang Xuequan, 2002, P88)

$$\begin{aligned}\Delta l &= 4R\sin\theta\cos\theta\tan\alpha = 4\times 0.9\times \sin 35.264\times \cos 35.264\times \tan 4 \\ &= 4\times 0.9\times 0.5773\times 0.8165\times 0.0670 \\ &\approx 0.119 \quad \text{m}\end{aligned} \tag{24}$$

In formula: θ – Leaving angle of element in drum sieve (^{o})

n - Rotating speed of drum sieve (r/min)

The average moving speed of element P along z axis is:

$$\bar{v} = \frac{\Delta l}{t} = \frac{0.119}{0.883} \approx 0.135 \quad \text{m/s} \tag{25}$$

3.2 The relevant size calculation of drum sieve

In this chapter, some relevant size calculation can be found and proofread.

3.2.1 The estimated capacity of food waste treatment

Considering the average daily processing capacity of an urban waste treatment plant is about 100–200 tonnes, with the reason of that the actual production capacity of a drum screener is designed to be 10t/h. (Tang Hongxia, 2007, 77)

3.2.2 The density of urban food waste

Urban food waste in the natural state, the mass per unit volume is called garbage density. Garbage density can be changed according to different ingredients. The main components of China's urban food waste are the oil and water. The density of these components is relatively high. The general density of mixed food waste is approximately between 0.18 t/m^3 and 0.35 t/m^3. In the design of this program, the designed garbage density is (Tang Hongxia ,2007, 77)

3.2.3 The inclination of angle of drum sieve α

Assembling inclined angle of the the drum screener directly affects its forwarding distance along the axis when food waste completes a completive cycle in the drum body which further affect the standing time of the food waste in the drum, the production capacity of drum and sorting and screening efficiency. When the length of the drum body and rotating speed are under certain circumstances, increasing the inclination of angle makes inclined angle along the forwarding direction of materials increase which further increases the component force of gravity along the forwarding direction of materials. Besides improving the sliding velocity component or axially parabolic velocity component, it can also accelerate average speed of overall cross-section, shorten the standing time of materials and improve its throughput. However, if the installation angle is too large, the time of moving cycle of waste in the body drum will reduce and also decrease screening and sorting efficiency. When the inclination of angle is too small, there is the need to improve the rotating speed of the drum body in order to ensure that drum screener maintains the high processing capacity and increases of cycling times of food waste in the body of drum that is in favor of screening and sorting waste. Based on the some relevant materials in China, the inclination angle of drum sieve is 4^o. (Qian Yonggen, 2014, 77)

$$\alpha = 4^o$$

3.2.4 The diameter of drum sieve D

Based on empirical equation (Wang Mingsheng, 2007, 45):

$$D = \left[\frac{11.36 Q_m}{d_b F K_v g^{0.5} \tan\alpha} \right]^{0.4} \qquad (26)$$

In which:

$\alpha = 4^\circ$

$Q_m = 10/3600 \approx 0.00278 (t/s)$, mass flow

$g = 9.8(m/s^2)$

$d_b = 0.3(t/m^3)$

F - Filling coefficient, according to the experience. F = 0.25 – 0.33. F = 0.25% in this design

K_v - Velocity correction coefficients, from the experience, when $\alpha = 4°$, K_v = 1.6

$$D = \left[\frac{11.36 \times \left(\frac{10}{3600}\right)}{0.3 \times 0.25 \times 9.81^{0.5} \times tan4^{\circ}}\right]^{0.4} \approx 1.924^{0.4} \approx 1.3m \quad (27)$$

In order to get a good rate of breaking the bags, appropriately reducing the amount of filling materials is necessary. Meanwhile considering the expansion of equipment, the roller diameter of drum is chosen as (Sheng Jinlang, 2013, 69):

$$D = 1.8m$$

3.2.5 The length of drum sieve body L

The big difference between this design of scene and conventional drum screener is that there is no tool applied for breaking bags in the body of drum which brings some influences. They are:

(1) When machine used for breaking the bags instead of the original tools applied for breaking is installed in the drum, it will be unnecessary to consider the rate of breaking bags of original tools which can efficiently increase rotating speed of the drum screener.

(2) As the rotating speed is increasing, sorting and screening efficiency will be improved. Taking into account that large space occupied by the equipment, it must be a good choice to keep its efficiency by shortening properly the length of the drum.

Based on the previous experiences, the length of the drum has the close relevance to the sorting and screening efficiency and the diameter of drum. If the length is too short, it will be easy to reduce screening efficiency. Nevertheless, if its diameter is too small, sorting and screening efficiency will be affected. Hence it is extremely important to select a suitable diameter for length ratio of the drum body.

The length of the drum body can be obtained according to the following empirical formula (Sheng Jinlang, 2013, P88):

$$L = (3 \sim 5)\ D \qquad (28)$$

D – Diameter of the drum sieve (mm)

Considering the length of drum body it needs to be reserved a length margin and a non-screening area (such as drum ring, gear ring, etc.) must be included into it. So in this scene (Sheng Jinlang, 2013, P88):

$$L = 6500 \quad \text{mm}$$

Based on the domestic and international references, the wall thickness of the drum is chosen as (Sheng Jinlang, 2013, 88):

$$\delta = 8 \quad \text{mm}$$

Hence:

$$n_c = \frac{30}{\sqrt{R}} \bullet \sqrt{\cos\alpha} = \frac{42.3}{\sqrt{D}}\sqrt{\cos\alpha} = \frac{42.3}{\sqrt{1.8}}\sqrt{\cos 4} = 31.45 \quad (r/\min)$$

In formula: D – Radius of drum sieve (m)

α- The inclination angle of drum sieve (^{o})

Rotating speed:

- 1. Switch-plates: $0.5\ n_c = 18.5$ (r/min)
- 2. No switch-plates: $0.8\ n_c = 29.7$ (r/min)

So in the scheme, rotating speed of the drum sieve is

$$n = 29.7 \text{ r/min}$$

3.2.6 The design of the sieve holes of the drum sieve

(1) The size of sieve holes

Table 3.1 The contents of urban food waste with the range of different particles sizes

Classification of food waste	The contents of urban food waste with different particles sizes			
	>100 mm	60~100 mm	20~60mm	<20 mm
Paper	8.8%~11.3%	12.8%~14.2%	14.7%~16.3%	1.6%~2.5%
Organic materials	30.5%~35.9%	27.3%~30.7%	57.6%~59.7%	83.2%~90.5%
Fibres	3.1%~5.8%	9.6%~11.4%	0~2.9%	0
Plastics	38.3%~44.7%	36.8%~38.9%	14.5%~16.2%	1.2%~2.8%
residuum	1.6%~3.5%	6.2%~7.9%	1.3%~3.5%	0~1.2%
Rubbers	0	0	0~0.1%	0
Wooden cubes	0~0.4%	0~0.7%	0~0.3%	0~1.5%
Metals	0.1%~0.3%	0~0.5%	0.1%~0.2%	0~1.6%
Glasses	5.2%~6.1%	0~1.2%	0.5%~0.7%	0~1.8%
Minerals	0.9%~1.8%	0~0.4%	0.4%~0.6%	0~1.7%

As shown inTable 3.1, in comparison with urban food waste without screening and sorting, after-sorting and after-screening materials with recycling potential are relatively concentrated in the appropriate range of size. After being sorted and screened by the drum screener, relatively concentrated food wastes with range of different sizes of particles are processed in the different methods to the treatment and further maximized the utilization of materials possessing recycling potential in the municipal solid wastes.

According to the Table 3.1, it can reflect the sizes of particles in the municipal solid refuses. In this scene, the sizes of sieve holes are chosen as:

$$d_1 = 80 \text{ mm}$$

$$d_2 = 200 \text{ mm}$$

$$d_3 = 300 \text{ mm}$$

d_1 - the diameter of a small size drum sieve (mm)
d_2 - the diameter of a medium size drum sieve (mm)
d_3 - the diameter of a big size drum sieve (mm)

(2) The distribution of sieve holes

When it comes to the domestic and international research on sieve holes, few engineers are interested in researching the distribution of sieve holes. In this scenario, the design and distribution of sieve pore in the plate-type screeners are used for the reference. When the distribution of sieve holes is based on regular triangle arrangement, it can extremely ensure that there is the uniform distribution of stress of a drum screener created by the gravity of food wastes among the sieve holes. Besides compared with the conventional arrangement of sieve holes, this special type of distribution has much more sieve holes. The more sieve holes it possesses, the higher efficiency of sorting and collecting it can create. With this reason, in this scenario, the small sized and medium sized sieve holes are all designed to be regular triangle distribution.

According to the above design notion, the three types of sieve holes can be designed with different diameters and numbers. The numbers of them are 320 (d_1 = 80), 100 (d_2 = 200) and 48 (d_3 = 300) respectively. Each type of sieve holes with different size will distribute on the same area on the surface of the drum. In order to achieve stepwise classification and screening that big size food wastes firstly are collected and screened then the medium sized food wastes and separation of small sized food waste is the last step, The food wastes should firstly come into the screening area with the big sized sieve holes and come out from the screening area with the small sized sieve holes by passing through the screening area with medium sized sieve holes. For the sieve hole, the distribution, shapes and sizes of and order of coming in can be shown from Figure.3.7, Figure.3.8, Figure.3.9 and Figure.3.10.

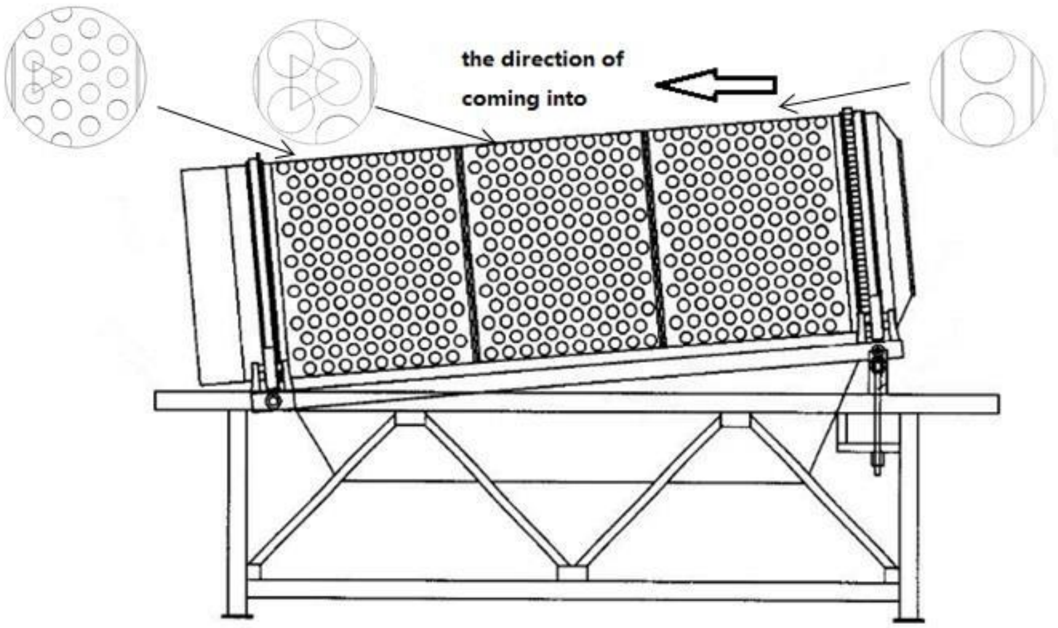

Figure.3.7 The drum screener and its sieve holes distribution (Yaoxuan Zhu, 2015.)

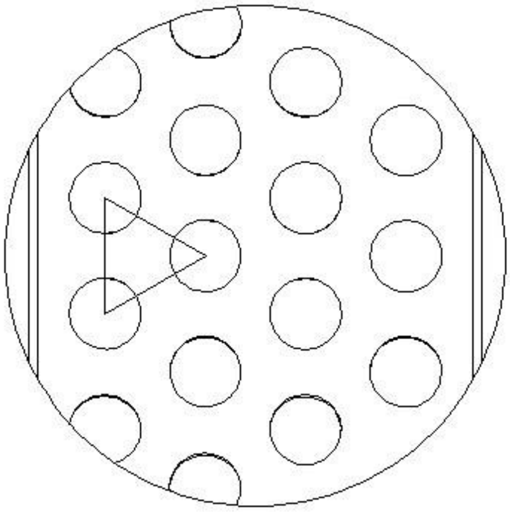

Figure 3.8 The regular triangle distribution of the small sized sieve holes (Yaoxuan Zhu, 2015.)

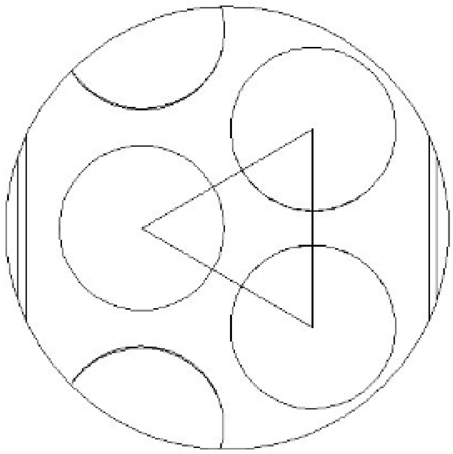

Figure 3.9 The regular triangle distribution of the medium sized sieve holes (Yaoxuan Zhu, 2015.)

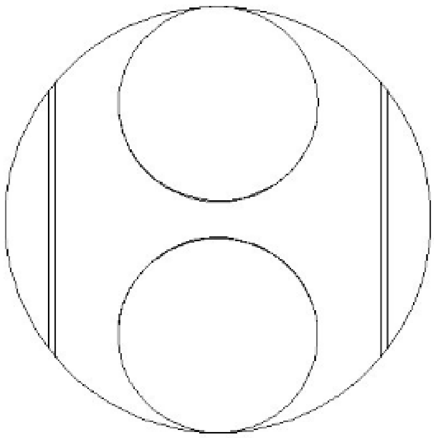

Figure 3.10 The regular triangle distribution of the big sized sieve holes (Yaoxuan Zhu, 2015.)

3.3 The calculation of weight of food wastes in drum and its electromotor capacity

3.3.1 The weight of food waste in the drum sieve

The amount of food waste entering into drum sieve will directly affect the sorting and screening efficiency. When the entering amount is less, sorting and screening efficiency will be reduced. However, if excessive amount of food wastes enters into the drum, the inner layer of trash will interfere the movement of outer layer of trash, and the effective recycling of food wastes in the drum will be broken. Meanwhile, sorting and screening efficiency will also be reduced. So the appropriate amount of food wastes into the drum must be determined by the practical processing requirements which can be calculated by the following formula (Qian Yonggen, 2014, 79):

$$G = \frac{FLd_b \pi D^2}{4} = \frac{0.25 \times 0.3 \times 6.5 \times 1.8^2 \times \pi}{4} = 1.24\ t \quad (29)$$

Where G – the weight of food wastes in the drum (t)

F - Filling coefficients (%)

L – The length of drum sieve (m)

D – The diameter of drum (m)

d_b – The density of mixed food waste (t/m^3)

3.3.2 The electromotor capacity of drum sieve P

The capacity of the food waste drum sieve can be calculated according to the empirical equation (Zhang Zhen, 2013, P89):

$$P = 746 \times 10^{-2} \times F \times G \times \sqrt{D} = 746 \times 10^{-2} \times 0.25 \times 1.24 \times \sqrt{1.8} = 3.1\ kw \quad (30)$$

In the formula: F - Filling coefficients (%) (25%)

G – The weight of food waste in drum sieve (t)

D – Diameter of drum sieve (m)

The production capacity and motor capacity of the food waste drum sieve should satisfy the requirements presented in Table 3.2.

Table 3.2 The relationship of production capacity (t/h) and motor capacity (kw) (Wang Mingsheng, 2007, P78)

Production capacity	≤15	≤20	≤ 25	≤ 30
Motor capacity	≤ 5.5	≤7.5	≤11	≤15

According to the requirements of Table 3.2, this scheme selects QABP200L-4A horizontal adjustable-speed motor as its standard motor.

Rated power:

$$P = 5.5 \quad \text{kw}$$

3.4 The basic size calculation of bag breaker

In this scheme, the handling capacity has been worked out which is:

$$Q_m = 10 \text{ t/h}$$

The transformation between handling mass (mass flow) and volume flow is:

$$Q_n = \frac{Q_m}{d_b} \quad (31)$$

$$= \frac{10\ t/h}{0.3 t/m^3}$$

$$= 33.3 m^3/h$$

d_b - Density of food waste (t/m^3)
Q_m – Handling mass of drum (mass flow) (t/h)
Q_n – volume flow (m^3/h)

The area between two shafts in the bag breaker (breaking area):

$$S = \frac{Q_n}{3600\bar{v}} \quad (32)$$

$$= \frac{33.3 m^3/h}{3600\bar{v}}$$

$$= \frac{33.3\, {m^3}/{h}}{3600 \times 0.2}$$

$$= 0.46\, m^2$$

$\bar{v}$ - Axial motion velocity of food waste (m/s) (0.2 m/s)

This bag breaker is assembled by four shafts which are divided into two groups (each two shafts in the same layer). The upper group can be used for breaking big bags and the under group can be applied into breaking the small bags. Based on the size of plastic bags of urban food waste in the daily life, the breaking area of bags are:

$$\begin{cases} S_1 = 0.8 \quad m^2 \\ S_2 = 0.4 \quad m^2 \end{cases}$$

In the formula: S_1 – Breaking area of bags in the upper layer
S_2 – Breaking area of bags in the under layer

According to the previous experience and real situation, the length of shafts in the bag breaker is:

L = 1800 mm

Hence, the distance between shafts is:

$$\begin{cases} a_1 = \frac{S_1}{L} = \frac{0.8\,m^2}{1.8\,m} \approx 444\,mm \\ a_2 = \frac{S_2}{L} = \frac{0.4\,m^2}{1.8\,m} \approx 222\,mm \end{cases}$$

In the formula: a_1 – the distance between shafts of upper layer
a_2 – the distance between shafts of under layer

By rounding the numbers:

$$\begin{cases} a_1 = 450 \quad mm \\ a_2 = 225 \quad mm \end{cases}$$

The figure below shows the internal structure of a four shaft bag breaker

Figure 3.11 The internal structure of a four shaft bag breaker (oharacorp,2015.)

4 THE RELEVANT CALCULATION AND PROOFREAD

4.1 The calculation of diameter of gear shaft

In this scene, the materials of shafts used in the gearing devices and roller mechanisms are all 45 steel. From the <The design of machines> handwork, the calculating equation of strength of gears (Wang Mingsheng, 2007, P45):

$$d_0 = A\sqrt{\frac{P}{n}} \quad (33)$$

$$d_0 = 70 \bullet \sqrt{\frac{5.5}{45}}$$

$$\approx 24 \quad mm$$

In which: d_0 - The diameter of shaft (mm)

A – Coefficient, A = 70

n – Rotating speed of shaft (r/min)

P – The transmission power of shaft, P = 5,5kw

4.2 The calculation of overall weight of drum screener

Based on the calculations in Chapter 3, it is known that:

D = 1800 mm

L = 6500 mm

d_1 = 80 mm

d_2 = 200 mm

d_3 = 300 mm

$\delta = 8 \quad mm$

D – The diameter of drum (mm)

L – The length of drum sieve (mm)

d_1 – The diameter of the small-size sieve holes (mm)

d2 –The diameter of the medium-size sieve holes (mm)

d3 - The diameter of the big-size sieve holes (mm)

δ - The thickness of drum sieve (mm)

However, the body of the drum screener is steel of S235-JR, The density of S235-JR is:

$$\rho = 7.85 \quad \mathrm{g/cm^3}$$

The volume of steel required for producing a drum (Wang Mingsheng, 2007, 45):

$$\mathrm{V} = \pi R^2 L - \pi(R-\delta)^2 L - \pi N_3 {r_3}^2 \delta - \pi N_2 {r_2}^2 - \pi N_1 {r_1}^2 \delta \quad (34)$$

$$= 6.5\pi \times 0.9^2 - 6.5\pi \times (0.9 - 0.008)^2 - 48\pi \times 0.15^2 \times 0.008$$

$$-100\pi \times 0.1^2 \times 0.008 - 320\pi \times 0.04^2 \times 0.008$$

$$= 227602\ cm^3$$

Where: N_1 – The number of small sized sieve holes, $N_1 = 320$

N_2 – The number of medium sized sieve holes, $N_2 = 100$

N_3– The number of big sized sieve holes, $N_3 = 48$

R – Radius of drum sieve (m)

L – The length of drum (m)

δ - The thickness of the drum sieve (m)

According to the empirical formula (Wang Li ,2008, P55):

$$\mathrm{m} = \rho V$$

Obtaining:

$$\mathrm{m} = 7.85\mathrm{g}/cm^3 \times 137457 cm^3 = 1079037.45\ g \approx 1079\ kg$$

4.3 The proofread of shafts

4.3.1 The proofread of shafts in the gears device

From the calculating formula of moment external force (Wang Li ,2008, P56):

$$\{M_\mathrm{e}\}_{N\bullet\mathrm{m}} = 9549 \frac{\{P\}_{\mathrm{k}W}}{\{\mathrm{n}_0\}_{\mathrm{r/min}}} \quad (35)$$

Where n_0 – rotating speed of drum sieve electromotor, n_0 = 600 r/min
Putting into:

$$M_e = 9549 \times \frac{5.5\ kw}{600\ r/min} \approx 87.5\ N.m$$

The maximum stress formula of torsion of the round shaft is:

$$\begin{cases} \tau_{max} = \frac{M_e}{W_t} \\ W_t = \frac{\pi {d_0}^3}{16} \end{cases} \quad (36)$$

Where：W_t - Coefficient of cross section of torsion, m^3

Putting into data:

$$\tau_{max} = \frac{87.5}{\pi 0.03^3 / 16} \approx 16.5 \quad MPa$$

Referencing <Mechanical Design> handbook, the critical value stress of torsion in the round shaft is: (Wang Li, 2008, P65)

$$[\tau] = 30 \quad MPa$$

Hence:

$$\tau_{max} = 16.5 \quad MPa \leq [\tau] = 30 \quad MPa$$

After checking, the gear shaft can satisfy the conditions of strength.

4.3.2 The proofread of shafts in the bag breaker

Based on the function of external moment of shaft (M_e) (Wang Li, 2008, P55)

$$\{M'_e\}_{N \bullet m} = 9549 \frac{\{P'\}_{kW}}{\{n'_0\}_{r/min}} \quad (37)$$

In the formula: P’ – the power of motor, P’ = 5 kW

n'_0 – rotating speed of motor, r/min, n'_o = 540 r/min

Input into formula (Wang Li, 2008, P99):

$$M_c' = 9549 \times \frac{5}{540} \approx 88.42\,Nm \quad (38)$$

The function of maximum shear stress of the shaft in torsion:

$$\tau_{max}' = \frac{M_c'}{W_t}$$

$$W_t' = \frac{\pi {d_o'}^3}{16} \quad (39)$$

W_t - Section modulus in torsion (m^3)

d_0 – The diameter of shafts in the bag breaker, d_o = 180 mm

Putting the data into the function:

$$\tau_{max}' = \frac{88.42}{\pi\, 0.18^3/16} \approx 7.7\,MPa$$

Based on the book of “Mechanical design”, the critical value of shear stress of shaft in torsion can be found: (Wang Li, 2008, P65)

$$[\tau] = 30 \quad MPa$$

So:

$$\tau_{max}' = 7.7\,MPa \;\leq\; [\tau] = 30\,MPa$$

After checking, the strength of shafts of a bag breaker can satisfies the required strength.

4.4 The operation and maintenance of the drum

Table 3.3 The most frequently occurred faults, causes and methods to treatment (Zhang Zhen, 2013, P99)

Occurred failure	Cause of failure	Solution to the failure
Rattling noise	The bolts of equipment are loosen	Re-tighten the bolts or use other fasteners
Wrong rotating direction of drum	Wrong connection of motor power cables	Replace any two power cables in the junction box
Low starting of motor	1.Transporting quantity is over the allowable value 2.Motor overload 3.The starting torsion is not enough	Re-adjust the transporting quantity
Gear box heating	1. Lack of lubricant 2. Low efficiency of ventilation in cabinet	1.Add more lubricant 2.Check and adjust the heat dissipation of vent
Electromotor heating	1. Cooling time of motor is too short 2.The working environment of motor ≥40℃ 3.Motor overload 4.The connecting line of motor is loose	1. Clean motor fans used for heat dissipation 2. Check whether the impeller of fan works properly or not and ensure patency of fresh air 3. Reduce load 4. Fasten the connections
Large working noise of drum	Check the roller and the right distribution of lubricant in each place	1. Add lubricant，if roller is worn seriously, no hesitation to changing it in time
Bearing heating	Check whether bearing lubricant is assigned into the right place	1. Add lubricant, if bearing is worn badly, immediately replace

5 THE ENVIRONMENTIAL AND ENCONOMIC BENEFITS OF DIFFERENT FOOD-WASTE TREATMENT METHODS

5.1 Landfill

The economic advantages of one of food-waste treatment methods - landfill are no pretreatment and low cost. However, its drawback is the need of large area of ground. In a well-designed landfill, approximately the 66 % of landfill gas can be collected and become a fuel and the rest (34 %) will go into the atmosphere. According to the survey, after landfilling each ton of food wastes, 250 m^3 of gas will be produced in which the main components of landfill gas are CO_2 and methane that account for about 60 % (volume fraction). The low calorific value of landfill gas is 14900 kJ/m^3. But the low heat value of natural gas is 37300 kJ/m^3. The low heat value of gas produced by each ton of landfilled food waste is the same as the low heat value created by combusting 99.9 m^3 of natural gas. The 500 tonnes food wastes landfilled daily will produce 1.25 × 105 m^3 gases. Besides, according to 66 % efficiency of collection and utilization, these landfill gases can replace the usage of the natural gas with the amount of 1.2 × 107 m^3 per year. Furthermore the current price of natural gas is about 3.45 RMB/m^3N. Hence tens of millions RMB of economic benefits annually will be generated. If these landfilled gases are used for power generation and efficiency of power generation is based on 30 %, the annual generating capacity will reach 3.74 × 107 kW•h. Furthermore, if the price is calculated by 0.56 RMB / (kW•h), the total annual generation revenue will be 2094 million RMB. Apparently, if landfilled gases produced by food wastes can be efficiently utilized like the above description, the considerable economic benefits will be produced. (ShiWaiTaoYuan,2015.)

Apart from that, once the leakage of landfilled gases happens, it will undoubtedly have an adverse influence on the environmental protection. On the other hand, land resources in most cities are relatively scarce and their price is too expensive. Besides the amount of processing, many existing landfill area is saturated. The impact of the environment and water resources generated by leachate coming from landfilled food wastes is also very serious. Therefore, food waste landfill treatment is an unsustainable development model.

If the food waste is landfilled underground, the annual amount of landfilled gas leaking into air is near 1.55 × 107 m^3 which contains 9.31 × 106 m^3 methane and 6.2 × 106 m^3 CO_2. Nevertheless the annual emission of CO_2 is about 3.01 × 107 m^3 when the landfilled gas is used to generate the power. So in the process of food waste landfill and power generation by the landfilled gas, the total annual CO_2 emissions are approximately 3.63 × 107 m^3 (equivalent 71772 t). In addition, there will be millions tons per year of leachate seeping into the groundwater which contains a large number of COD, BOD5 and other pollutants. It is a serious threat to the safety of groundwater resources. (ShiWaiTaoYuan,2015.)

5.2 Incineration

The economic advantage of incineration of food waste is that in the incinerator, at a high temperature, the organic materials among the food wastes will be thoroughly oxidized and decomposed to achieve reduction in volume and quantity. Besides, the heat generated during this process can be used to generate electricity and heating. Garbage incineration has a high requirement for moisture content of garbage. However, low calorific value of food waste is not more than 3000 kJ/kg. Even if after the drain, it also cannot meet the requirements for incineration. Hence fuel is needed to help combustion that is undoubtedly increases food waste disposal costs meanwhile some pretreatment works also are needed to be done such as reducing the moisture of food waste by squeezing and draining and improving the calorific value by using the rest of heat which comes from the blast furnace. After these pretreatment works, its moisture content will be reduced to about 40 % and its quantity will also be reduced to 2/3.

According to the 500 tons daily treatment capacity, after pre-treatment, the daily amount of food wastes can reach 333 t and have 4890 kJ/kg low calorific value. With this scale of daily handling capacity, the heat generated after the pre-treatment of food wastes can drive one group of turbines with 6 MW to produce the electricity with 30 % efficiency. Besides each ton of food wastes after incineration can generate 407 kW•h every day or 4.95×10^7 kW•h each year. So the annual power generation can achieve 27.73 million RMB revenues. (ShiWaiTaoYuan,2015.)

In the terms of environmental part, by the assumption that combustion efficiency of blast furnace is 90 %, after burning each tonne of food waste will produce 0.08 t ashes and emit 0.708 t CO_2, 2.4 kg SO_2 and a certain amount of NO_X. Based on this calculation, the annual emission of CO_2 and SO_2 will reach 86000 t and 295 t.

5.3 Food waste recycling treatment

Compared with ordinary diesel, biodiesel can reduce CO_2 emissions by 78 %. However, by mixing biodiesel with ordinary diesel based on 1: 4 (volume ratio), the combustion performance can be maximally optimized which leads to 15.6% reduction of CO_2 emissions. Density of biodiesel is about 0.85 kg / l, according to the sale price - 4 RMB each liter, the annual profit generated by the integrated biodiesel coming from food waste will be 47.75 million RMB. One tonne of food waste through anaerobic fermentation and gas separation can produce biogas (29000 m^3) which has low calorific value (35000 kJ/m^3). According to 500 t daily handling capacity, after treatment, these food wastes can produce high-purity methane which can provide energy for a 6 MW steam turbine to generate power. Besides its efficiency of power generation can reach 40 %.

In addition, this kind of food waste recycling treatment not only can reduce the emission of CO_2, in some extents, but also can recycle the CO_2. If each tonne of food wastes through anaerobic fermentation can produce 77.8 m^2 and volume ratio of methane and CO_2 is 3: 1, each year there will be 7000 t CO_2 produced as industrial raw materials. Compared with the ordinary diesel, the biodiesel produced by the food waste recycling treatment can reduce CO_2 emission annually by 110000 t. (ShiWaiTaoYuan,2015.)

6 THE MARKETING PERSPECTIVES OF FOOD-WASTE TREATMENT EQUIPMENT

When observing the problems and characteristics of food waste, food waste treatment equipment is developing to achieve further miniaturization, integration, automation and suitable for families or small-scale units in order to deal with the daily organic food wastes. Food waste treatment may develop in the following directions for future. (Meng Baofeng, 2009, 88)

1) Miniaturization and high integration: Due to the limited size of the kitchen the average family or general catering units, processing equipment volume has too much effect on the daily operations of the kitchen, so a higher degree of integration diversified processing approach and smaller floor space will be developing trends of food wastes disposal equipment in the future.

2) High intelligence: In order to improve the effect of food waste treatment, it is necessary to meet the suitable conditions for the biological degradation treatment. But because there is a big difference between different compositions of food wastes resulting in different treatment methods which require processing should automatically change the processing program according to the different material in order to achieve efficient food wastes intelligent processing.

3) High automation: Due to the high organic content, food wastes in the appropriate temperature and humidity conditions, are vulnerable to go bad. If the operator frequently has contact with them, the operator will have health threat. Thus a high degree of automation is necessary.

4) Low energy consumption and low running costs: Development of small food waste treatment equipment to achieve the in situ treatment of food wastes, effectively overcome the large-scale production line problems in collection and transportation, reducing transportation costs; and also to overcome the shortage of food waste materials. If we can further reduce power consumption devices, it will have a wider range of applications.

7 THE CONCLUSION

The design of pre-treatment food wastes equipment mainly focuses on the re-design of the drum sieve and the bag breaker. Due to the sophisticated design and manufacture of other accessory parts, there is no need to re-design them but just follow the traditional design of these accessories. When it comes to the re-design of drum sieve, it is a little bit different with the traditional drum sieve design. The difference is that there are no any tools designed for breaking bags in the new drum. The advantage of this way is to dramatically increase the rotating speed of drum sieve and to ensure that when decreasing the length of the drum sieve, its handling capacity will simultaneously not be reduced. In this situation, not only the drum sieve will be designed but the new sole bag breaker will also be made.

The calculation specification is about the drum sieve design in the whole system of food waste recycling treatment design. Based on the handling capacity required by the main task, the structure size of the drum sieve is calculated. Meanwhile some necessary strength checks or proofreads are done. The ultimate goal is to produce the drum sieve equipment that can be used in the real daily life. The main steps of design can be shown below:

1) The designing scheme: Designing relevant parameters.

2) The calculation of the whole process: Calculating drum sieve, the inclination angle of drum, its power capacity of motor and so on.

3) The design of the drum sieve structure: According to the required handling capacity of food waste, the calculation of length and the diameter of the drum sieve can be done. After the research into the characteristics of urban food waste, the suitable size of sieve holes can be easily found out.

4) Accessary parts design: Designing of a bag breaker, a machine frame, a gears device and a roller de-vice.

5) The manufacture and installation of the drum sieve, some relevant inspections and maintaining and some notices about daily operation.

6) The introduction to the relevant food waste equipment and the marketing analysis and potential perspective research of our new equipment.

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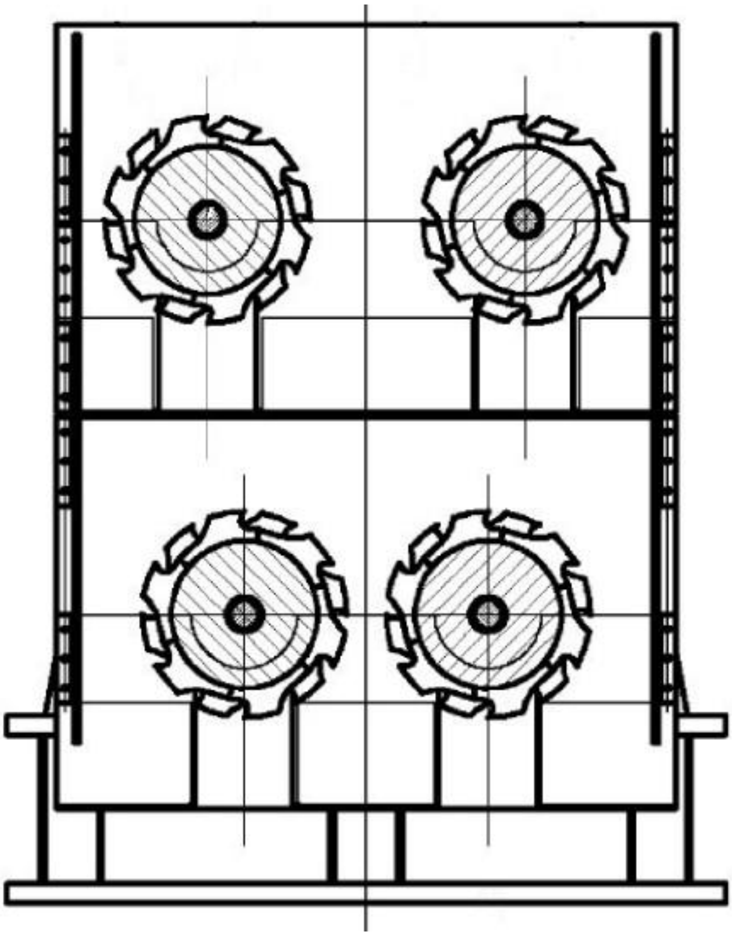
Figure 3.5 The analysis of motion of materials in the sieve drum, [Read 26.3.2015]. Available: http://xihuashe.analysis of motion.com/link

Figure 3.10, The introduction to the bag breakers, [Read 26.3.2015]. Available: http://www.oharacorp.co.jp/en/products/recycle/2axis_bag_breaker/

The introduction to different food waste treatment methods and their economic benefits[Read 26.3.2015]. Available: www.fairyland.com.cn/newshow.asp?id=233

Appendix A The internal structure of four shafts bag breaker



Appendix B The Three View Drawing of Drum Sieve Machine