Design and Experimental Research of Micro Solar Power Contact UASB

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Abstract

In the thesis, solar photo voltaic is served as the heat energy of contact UASB reactor. The authors design an integrated device to treat dispersing domestic sewage such as the sewage in residential communities, military camps, sentry posts and stations Etc. This device uses solar energy (1,000W) to warm up and maintain the degree of reaction system at a medium temperature (35□), and then it can rapidly decompose the organic matters of domestic sewage (1m^3/d) in the anaerobic environment and transfer these matters into CH_4, CO_2, H_2S and NH_3. At the same time, the noxious gas H_2S and CO_2 will be absorbed, and then discharged. Designing, making and starting the device show that the process and device is successful. The device is characterized by low cost, stable operation and high efficiency when it is used to treat domestic sewage of low concentration, low amount and low temperature. The result of starting-up experiment at normal temperature(15□) shows when we use glucose water to simulate the domestic sewage and controlling the inflow COD at 500mg/L, the removal rate of inflow COD will reach 71.2% and the peak pressure of gas will reach 1kPa. If the reactor runs for a month and the inflow pH is controlled between 7.5 and 8.0, the reactor will run normally and stably.

Key words: solar photo voltaic; contact UASB reactor; starting-up experiment

Introduction

Making a general survey of the sewage treatment history, the treatment capacity should also not be ignored apart from the sequence of the thought for technical development. Seen from the respect of waste water treatment technology, land irrigation system was applied in the Intransigent England for rosewater treatment in the year of 1829; Then in the 1850's horizontal sedimentation tank was invented; In the year of 1860, one kind of rosewater penetration well was designed by L. H. Amours in France; in the year of 1895, Donald Cameron applied the patent of digestion tank; in the year of 1870, Edward Frank land carried out the filtration fundamental research, in 1960's chemical precipitation method was gotten applied widely along with flowing into urban sewage treatment plant of a large quantity of industrial waste water; After WWII, in order to avoid water body catastrophic, SBR□CAST etc process were formed to apply the computer model and automatic control into rosewater treatment. Standing at the sides of scale, after having passed through distributed processing, large scale concentrate type rosewater treatment started from 1980's and along with expansion of rosewater treatment scale, collection, transportation and storage of large quantity of rosewater confronted with problems of enormous pipe network system and huge investment and management and operation cost. On the other hand, discharge rosewater monsieur at suburb, village and military camp and post where are far away from the urban pipe network system has caused new pollution. Decentralized system for rosewater treatment caused attentions of people once again with the following features: it can be applied widely without being limited by pipe network distribution; it is suitable to different water quality and water volume; treated rosewater can be used recycling once again. Comparing to centralized municipal rosewater treatment system, decentralized rosewater treatment system has the following advantages: lower investment, shorter construction period and quicker affectation; system can be integrated or containerized or underground; less investment for rosewater treatment and reuse is easy for reusing water resources; suitable to decentralized rosewater discharging resources in the area with lower population density[1].

In recent years, energy and resources crisis are increasingly prominent along the world. With the development of the subjects of microbiology, biochemistry etc in the field of rosewater treatment,the research people did to anaerobic biological treatment keep progressive,which has prompted a series of high-rate anaerobic reactor's research and development which is based on microorganism immobilization and increasing mixing rate between sludge and waste water.AFBR),anaerobic filter (abbreviated as AF), up-flow anaerobic sludge bed reactor (abbreviated as UASB) and expanded granular sludge bed reactor (abbreviated as EGSB) [2] .

However the biological reaction has shortcomings of longer reaction time, poor adaptation and lower efficiency, combination between solar electric direct conversion and modified UASB can be not only suitable for waste water with high load and mass flow but also suitable for domestic rosewater with decentralized low load and flow rate which can shorten the treatment cycle, increase the three phase separation efficiency and decrease the treatment cost and operation cost. There is a broad application prospects for UASB especially in the regions with poor economic technical base, imperfect networks of drains, unavailability of rosewater treatment plant and quite a lacking sewage treatment facility.

1. Optimal Design Of UASB[3]

1.1 Selection of Design Parameters

The treatment object of UASB in this paper is domestic rosewater with design treatment volume of daily domestic water consumption for 5 persons and design flow of the UASB in this paper as Q=40L/h, according to daily water consumption 200L/d for each people given by building water supply and drainage water quota in the 2nd Vol. of Design Handbook of Water Supply and Drainage.

The COD of domestic rosewater is less with 200-1000mg/L normally and typically 500mg/L, thus 0.6kg COD/m3·d is selected as COD cliometric loading UASB and Designed confluent quality is given in Table 1.

Table 1 Design Index for UASB

Index	Inflow Water COD (mg/L)	Outflow Water COD (mg/L)	Removal Rate □%□	Gas Yield □ppm□	Reaction temperature □□□
Quantity	500	50	90	100	35

1.2 Effective Volume Design

Volume Design for UASB in the paper is according to cliometric loading method:

$$V_1 = \frac{Q(C_i - C_o)}{N_v} \qquad □1□$$

Given as□

V_1 - Effective Volume of Reactor,m^3□

Q - Design flow of waste water□1m^3/d□

N_v - Volume Loading Rate□kg COD/m^3·d□

C_i -Concentration of Inflow water COD ,mg/L□

C_o -Concentration of Outflow water COD,mg/L.

Effective Volume of reactor is: 0.75 m^3.

The loaded liquid volume for the reactor is 70-90% in general, i.e. the effective cliometric coefficient is 70%-90%. The 80% of loaded liquid volume is selected in this paper and the effective volume in this paper is 0.60m^3.

1.3 Determining Geometric Dimension

Round arrangement with stable structure and uniformity of water distribution etc is adopted on the UASB reactor. Given the diameter of 0.6m and then the effective height is□

$$V = \frac{\pi D^2}{4} \times h \qquad □2□$$

Among them, h=1.59m, the total height UASB is equal to the effective height H then ,H=h+h1+h2, then h1 is the height of gas and liquid separation and given 0.3m and then h2-protection height given 0.1m.Finally, H has gotten 2m.

Table 2 Main Design Dimension & Parameter Table for UASB Reactor

Parameter	Effective Volume (L)	Height of Main Body (mm)	Diameter (mm)	Cliometric Loading (Cod/m^3·d)	COD Removal Rate (%)
Value	750	2000	600	0.60	90

1.4 Structure Design Of UASB Reactor [4]

Design purpose of Three Phase Separator is to separate the methane from the miscible liquids and floating sludge and get the sludge subside as far as possible and then return to reaction area. Although there are many design forms of Gas-solid fluid three-phase separator however the general design principle is as follows[5,6]: (1) the angle between bevel and horizontal direction of three phase separator should be 45-60 degree and be smooth for sludge gliding down back to reaction area and the included angle in this paper is 52 degree; (2) Overlaps between bevel plane and sedimentation skew wall should keep certain width to prevent the gas from entering into settling chamber and the width designed in the paper is 100mm; (3) Gas-liquid phase interface in gas collection chamber should be hold stable to release the bubble and get cross the scum layer; (4) the diameter exit pipe of three phase separator should be big enough to enable to send out the gas easily while there is foam. The sediment pipe should be installed inside the exit pipe to make the sludge and scum return back and the diameters for exit pipe and sediment pipe are 100mm and 60mm; (5) Exhaust Treatment Device is installed on the top of reactor, refer to Fig 1.

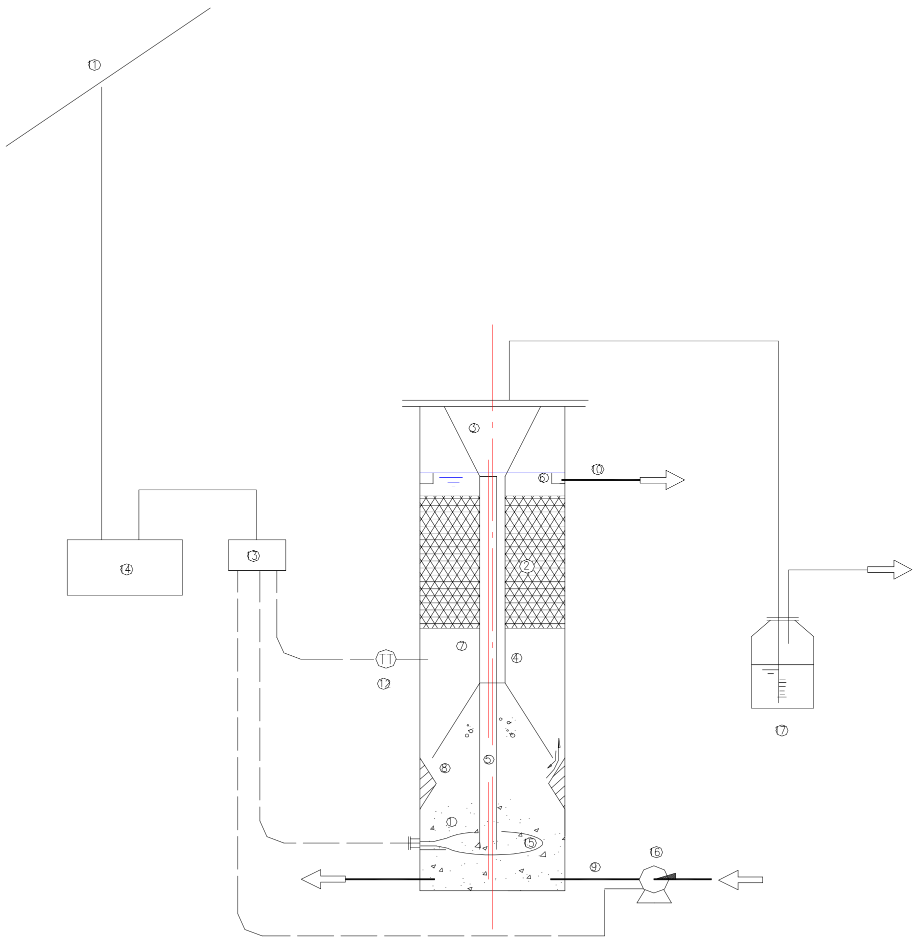

Fig 1 Design Schematic Diagram for UASB Reactor

(1)The First Reaction Area(hydrolysis Reaction); (2)The Second Reaction Area(anaerobic digestion Reaction); (3)Gas-Liquid Separation Chamber; (4)cum Riser Pipe; (5)Down comer; (6)Down flow Weir; (7)fretting Zone; (8)Three Phase Separator; (9)Inlet Tube; (10)Discharging Tube; (11)Solar photo voltaic panels; (12)Dual Metal Temperature Sensor; (13)Control Cabinet; (14)Storage battery; (15)Electrical Heating Rod; (16)Feed Pump; (17)Exhaust gas canister.

The hydrolysis reaction between water and sludge has been carried out on domestic rosewater which has entered into the first reaction area via inlet pipe, most of organic compounds has been hydrolyzed in this segment. The rosewater has entered into the first reaction area and formed thermal cycle through heating rosewater in the first reaction area with electric heating rod powered by Solar photo voltaic Electric Heating Appliances set outside of the reactor at the 35degree controlled by temperature control cabinet (13). The rosewater is separated into three phases of water, mud and gas in three phase separator (8) and then water phase has entered into settling zone (7) for sediment to reach the slurry separation and gas phase has entered Dino gas-liquid separation chamber (3) via riser Pipe (4) along with the liquid for gas and liquid separation, separated gas is exhausted via exhaust gas canister and separated water is returning back into the first reaction area for repeat treatment via down comer(5) and separated rosewater is entering into the second reaction area for anaerobic digestion Reaction. The micro-biological degraded rosewater can be standard discharged through Downs weir.

Bio-contact oxidation filler area with 2×3cm columnar PVC filling materials with 600mm high is installed on the upper part of the reactor in this paper. The organic matters absorbed and resolved in the rosewater during the course of contacting between rosewater and biological membrane which is formed in the filler area has enhanced the mass transfer process between microorganism and organic matters. The scum down comer setting in the top of reactor make the scum rising along the gas back to the settling zone to increase the three phase separation efficiency.

1.5 Material of UASB Reactor

Considering of the possible codification reaction may occurred during the course of rosewater treatment in the UASB reactor, thus more cares should be taken to select the materials of the equipment. The fiberglass is selected as main material of the equipment because of large strength ,corrosion resistance and good transparency which make us enable observe the operation situation of the equipment and with good thermal insulation performance supported by external thermal insulation layer of 4cm thick soft foamed plastic(thermal transferring coefficient λ=0.05W/m·K). Design UASB reactor well will be manufactured by the subcontracting and manufacturing, assembling and inspecting of every components should comply with JB2932-1999 Manufacturing Technical Conditions for Water Treatment Equipment.

1.6 Design of photo voltaic system

The energy of UASB comes from the pump and heating device. Temperature is the most important factor when the anaerobic biological treats polluted water, good heating and moisturizing system could improve the reaction efficiency significantly.

(1) Heat design and calculation

1) Required energy of heating sewage[5]

The energy Ah heating 40L sewage from 20℃ to 35℃ every hour can be calculated as follows:

$$Q_h = \lambda_f C_f (35 - t) Q / 0.85 \quad (3)$$

Where Q is the sewage's flow, λ_f is the sewage's density which is set as 1000 kg/m3, Cf is the specific heat capacity of sewage which is set as 4200J/(kg.□), the sewage's temperature which is set as 20□.Take the thermal efficiency of 0.85, the calculated result of Ah is 857.8W.

2) Heat loss of reactor

The heat loss Q0 can be calculated as follows:

$$Q_0 = F \cdot K(T_2 - T_1) \quad \text{□4□}$$

Where K is the overall heat transfer coefficient, T2 is system temperature which is 35 □,T1 is ambient temperature which is set as 20 □.

Due to the flow velocity within the system is slow and the velocity of air outside of the system is close to zero and the material of the system is fiberglass, the thermal conductivity of soft foam insulation material is very small. Here we take the heat loss coefficient as 5% and the calculated result of Q0 is 42.89W.

3) Power calculation

The power of P can be calculated as follows:

$$P = Q_h + Q_0 \quad \text{□5□}$$

the calculated result of P is 900W.

(2)Kinetic energy device selection

Here we utilize peristaltic pumps whose model is JWM-A 6.5/1. The pump's nominal flow is 40L/h and its nominal power is 0.18kW.In summary, the total power the PV system should provide for the UASB is 1.08kW.

(3) PV system design

1) Component selection

According to the needed heat and kinetic energy, PV system's power is designed as 1.2kW in this paper. We select 12 photo-voltaic panels whose power peak is 100W and model is ICO-SPC-100W to construct the PV array and we select 8 batteries whose model is HGY6037 to storage the excess energy. As for controller and converter, we utilize Bossiness 48V-50A controller whose model is CP-04850 and Bossiness 2000W converter whose model is BN-20248[6].

2) Test and evaluation

Taking Xi'an as example, according to the software of PV system, the installation tilt of PV models is designed as 45°which can ensure winter's power preferentially. The wiring design of PV models utilizes four series, 3-way parallel. And the wiring design of battery utilizes four series, 2-way parallel. Through simulation, the system's expected generation capacity is tabled as follows.

Table3 expected generation capacity of designed PV system

month	Horizontal radiation kWh/m2	Excepted generation kWh
January	63.9	82.3
February	72.2	80.9
March	98.9	97.6
April	122.3	105.4
May	145.7	120.9
June	151.5	120.0
July	153.7	125.5
August	149.4	135.1
September	100.8	96.8
October	82.3	88.3
November	63.3	77.5
December	57.7	73.7
Year	1261.7	1203.8

As can be seen, the PV system's annual power generation is 1203.8kWh. Among them, the generating capacity is most strong in August, which reaches 135.1kwh all monthly and the energy can ensure the load operate 4.0h daily. In contrast, the generating capacity is most weak in December, which reaches 73.7kwh all monthly and the energy can ensure the load operate 2.0h daily.

2. Experimental Research [7]

2.1 Experimental Material

(1)Experimental Used Water: man-made glucose integrating with water and Carmelo, mono potassium phosphate are poured into solution to adjust inflow water COD: N: P=150:5:1 and then sodium bicarbonate is added in for regulating the inflow water pH Value.

In this experiment, we use low concentration man-made glucose integrating with water to simulate domestic rosewater, nitrogen element required by microorganism is provided by Carmelo and phosphorus is provided by mono potassium phosphate. Inflow water COD is controlled to 500mg/L. Chemical formula for glucose required by experiment is $C_6H_{12}0_6 \bullet 2H_2O$□the calculation of the Glucose degradation product is as follows .

$$C_6H_{12}0_6+2H_2O + 6O_2 \rightarrow 2CH_3CHCOOH + 2CO_2 + 4H_2 \quad (1)$$

$$C_6H_{12}0_6 + 2H_2 \rightarrow 2CH_3CH_2COOH + 2CO_2 + 2H_2O \qquad (2)$$

Calculation of COD required during complete oxidation of glucose:

$$C_6H_{12}0_6 \bullet H_2O + 6O_2 \rightarrow 6CO_2 + 7H_2O \qquad (3)$$

As per calculation mentioned above: m($C_6H_{12}0_6 \bullet H_2O$)□COD is around equal to 1:1 i.e. glucose adding volume into the inflow water is 0.5g/L and as per the COD:N:P=150:5:1 and adding volume of $CO(NH_2)_2$ is obtained 35.7mg/L and adding volume of KH_2PO_4 is 14.7mg/L.

(2) Inoculated sludge is taken from SBR Tank of the Rosewater Treatment Station in Northwest Nontechnical University, Chandigarh Campus with moisture content of 96%, TSS of 44.32g/L, VSS of 28.71g/L and the inoculated sludge volume in the reactor should calculate as per the VSS not less than 10g/L.

2.2 Analysis Item and Inspection Methods

COD□potassium achromatic method; TSS□VSS□geometrical method□pH□Type PHS-3C pH Meter; Gas flow: Hand held Digital Manometer; Temperature: by Fluke thermal infrared Image.

2.3 Experimental Apparatus

Rex Type PHS-3C pH Meter, INESA Scientific Instrument Co.□Ltd; Type SHANGPING FA1004 Analytic balance, INESA Scientific Instrument Co.□Ltd; Type Inhere CS101-2A Fan Blown Type Electric Drying Oven, Chongqing Inhere Experimental Equipment Co., Ltd. Type SX-4-10 Chamber Electric Furnace, Beijing Kewpie Ongoing Instrument Co., Ltd.

2.4 Test Method [8]

Firstly, cultivate inoculate sludge. Taken 2-3g mature sludge from SBR Tank of Rosewater Treatment Station of Northwest Nontechnical University, Chandigarh Campus into 20ml nutrient solution and then kept in incubator (30□) and cultivated for 3-6days;Secondly, confection and injection of Glucose solution (500mg/L) will be performed continually and Glucose solution is tending to acidic and pH Value is less than 7.0, thus pH Value can be adjusted to 8.0 through added sodium bicarbonate into regulating reservoir. As a general rule, pH value of outflow water from reactor is less than those of inflow water and thus at the same time of acceptation of partial flux and pH value can be adjusted to the optimal 6.8-7.2 inside reactor through adjusting inflow water pH value.Finally, temperature inside reactor should be kept not less than 35□ after turning on solar photo voltaic electrical heating system and at the same time the influence to reactor by poisonous and harmful substance and sulfate should be controlled.

3. Result and Discussion

3.1 Reactor Starbucks And Operation

Inoculated anaerobic sludge should be cultivated and acclimatized in the initialization phase in the reactor to make them accommodate inflow water quality thus initialization performance period is longer. The Reactor is running for 30days and the Inflow COD should be controlled at the concentration of 500mg/L before Starbucks and pH value of inflow water should be adjusted to the range of 6.8-8.0 through adding sodium bicarbonate and continual water feeding pattern is adopted in this paper to keep the inflow rate of 10L/h. Variation of COD between inflow and outflow and COD removal rate with time refer to Fig 2.

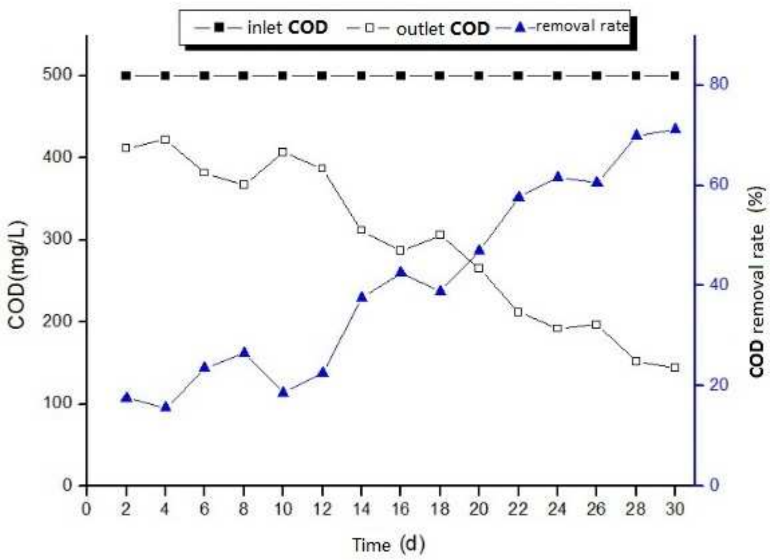

Fig.2 Variation of COD between inflow and outflow and COD removal rate with time

In the initialization phase of reactor, the microorganism has good adaptation for the inflow and removal rate increases step by step. In the beginning, because of lower gas production rate and reactor lack of power and removal rate mainly maintain around 20% in this phase. After several Day cultivation, gas production rate of reactor increases and bubble increasing to reaction area, sludge mixes rosewater completely to make the removal rate further decrease. It is observed that three phase separator can well separate the rosewater and sludge and sludge gliding along with bevel and sediment skew wall to stay inside reaction area to prevent the sludge loss effectively.

Comparing to precedents, it can be found from Fig 2 that the COD removal rate of reactor decreases while the reactor runs in the 10th day and 18th day. The main reason is that reactor runs at the ambient temperature and everyday average ambient temperature is different. Temperature is one of main factors influencing anaerobic biological treatment and has a large influence to COD removal rate of reactor and abrupt fall of temperature will has obvious influence to activity of microorganism and further influence reactor treatment effect.

Inflow and outflow water pH Value of UASB reactor is one of important indicator to measure if the reactor works stably. During the course of anaerobic treatment, both hydrolysis bacterium and acid-forming bacteria have bigger adaptation range to pH value and most of these bacteria can grow well within pH value range of 6.0-8.5. The suitable pH value for methane bacteria's growth is between 6.5 and 7.8 and the optimal pH value is between 6.8 and 7.2, Inflow and Outflow pH Value refer to Fig 3.

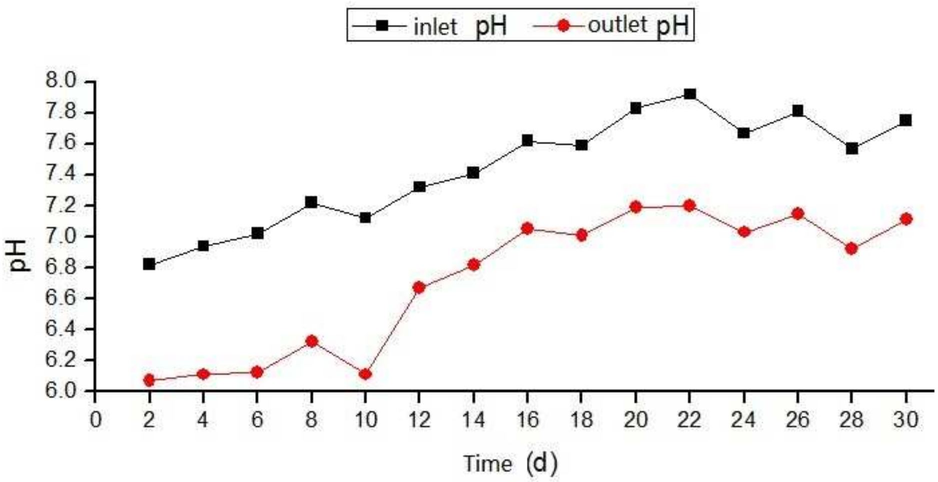

Fig.3 Variation of pH between inflow and outflow with time

It is observed from Fig 3 that in the beginning inflow pH value of reactor can be adjusted to the range of 6.8-7.2 and all outflow water pH values are kept around 6.2 and lower outflow pH value and longer time operation can restrain growth of methane bacteria. Anaerobic biological treatment can make the reactor pH value decrease and should take the inflow water with higher pH value to adjust the reactor pH value to 7.5-8.0 and outflow water pH value of reactor is kept around 7.0 shows the reactor runs stably. Thus provided that inflow water with higher pH value is utilized and better treatment effect can be achieved.

3.2 Conclusion

(1)Adding contacting anaerobic process in the second reaction area of the UASB reactor and scum return pipe in the gas-liquid separation can greatly enhanced the function of mass transfer and separations. (2) Energy source of UASB reactor is based on photo voltaic power system which can work for 4 hours in summer and 2hours in the winter in Xi'an City of China, but the actual run time implementation power was only 50%. (3) During the course of processing domestic rosewater simulated with 500mg/L glucose solution , the removal rate of COD inside reactor can reach more than 70%. (4) pH Value of inflow water adjusted to 7.5-8.0 and pH value of outflow water kept to around 7.0 are benefit for growth of methane bacteria and stable operation of the system.

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