Development and Evaluation of lab-scale model pH based Biphasic Anaerobic Bioreactor for Biogas generation from Cattle Dung

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Abstract

India having the largest livestock population in the world, offers a tremendous potential for the development of biogas units. Cow dung is generally used for the generation of biogas through anaerobic digesters, but high rate anaerobic reactors have not yet been used. Thus the pH based biphasic Moving Bed High Rate Anaerobic Reactor is developed taking into consideration the pH based phase separation and biogas generation in a short HRT as compared to conventional anaerobic digesters. The pH based biphasic MB-HRAR is a continuous feed plug flow batch reactor. In order to evaluate the performance of pH based biphasic MB-HRAR for generation of biogas, cow dung: water ratio 1:3 is used as the only substrate. Throughout the study period, the reactor is operated at ambient temperature having maximum temperature range of 31.4-46.8 °C during day time and minimum temperature range of 23.9-31°C during night time. The HRT is 23 days and the OLR is in the range of 1.6-1.8 gm COD/L.day. The pH is reduced to 5.5 by adding a mixture of sulphur based organic acid at a rate of 7 ml/day to help in hydrolysis and acidogenesis only. Gas mixing is provided by recirculation of the biogas produced in the reactor itself. In the laboratory, as it is not possible to compress and recirculate the biogas produced, nitrogen gas is passed as a substitute. The pH is increased to 7 by addition of lime at a rate of 10gm/day before the feed enters into the methanogenic compartment. The performance evaluation of the reactor showed a COD reduction of 64.29% and a TS reduction of 69.01%.

Keywords—Moving Bed High Rate Anaerobic Reactor (MB-HRAR), Organic Loading Rate (OLR), Hydraulic Loading Rate (HRT), Chemical Oxygen Demand (COD), Total Solids (TS).

1. Introduction

Biogas technology provides an alternate source of energy in India and is hailed as an archetypal appropriate technology that meets the basic needs. Realization of this potential and the fact that India supports the largest cattle wealth led to the promotion of biogas generation in a major way in the late 1970s as an answer to the growing fuel crisis.[1]

During the last 30 years, Anaerobic systems namely High-Rate Anaerobic Reactors that rely on the separation of solid retention time (SRT) from hydraulic retention time (HRT) have proven to be sustainable. Particularly, the UASB process, and its derivatives, have demonstrated excellent performance in numerous full-scale operations worldwide (Lettiinga, 1995).[3] Despite the success of these reactors, the need for other systems that allow generation of biogas within optimum HRT including optimization of each phase, proper mixing, heating, pH control and increased content of methane etc. is conquering great attention in research.

In the conventional biogas units, different types of anaerobic digesters are used to generate biogas. Moreover, the conventional biogas units have huge volume and require high construction cost as well as large land area which is accountable to 30 to 50 days HRT to generate biogas.[2] In case of anaerobic digestion, there is a delicate balance between these two groups of microorganisms (i.e. acidogens and methanogens), because they differ greatly in terms of physiology, nutritional needs, growth kinetics and sensitivity to environmental conditions.[10] Problems encountered with stability and controls in conventional one-stage reactors have led researchers to new alternatives. Therefore, providing the most appropriate environmental and operational conditions for each microbial community in two-reactor systems which are physically separated consequently has significant outcomes, such as increased overall process efficiency, stability and control, a higher specific activity of methane-formers in the methanogenic reactor, higher organic loading rates and a faster start-up of high-rate systems.[7][8] To minimize the HRT, optimize each phase and to reduce the volume, pH based Biphasic Moving Bed High Rate Anaerobic Reactor is required.

This study focuses on the pH based phase separation for generation of biogas from cow dung on which less work has been done so far. The primary aim of the study is to evaluate performance of the pH based Biphasic MB-HRAR for generation of biogas from cow dung at ambient temperature.

1.1 Unique features of pH based Bi-Phasic MB-HRAR

An attempt is made to design the laboratory scale working model of pH based Biphasic Moving Bed High Rate Anaerobic Reactor (MB-HRAR) during the study. The unique features of the pH based bi-phasic MB-HRAR are as follows:

i) **1:3 Cow dung slurry:** Such dilution is required to allow a flow in the plug flow reactor. Also at such a dilution, rate of hydrolysis increases.
ii) **Gas mixing:** There are no moving parts in the digester, thus results in long term reliability of operation and maintenance. Recirculation of the gas produced within the reactor also increases the efficiency.
iii) **pH:** Optimum pH required for each phase is provided which allows maintenance of appropriate densities of the acid and methane-producing microbes enabling maximization of their rates. Moreover, the acid phase and methane phase could be started much more easily and quickly than in conventional, single-stage digesters.
iv) **Recirculation of slurry:** This results in addition of active methanogens in the reactor leading to increase in biogas generation.
v) **Organic acid:** Mineral acids are not preferred. An organic acid is used which is accepted to help in hydrolysis.

The present study mainly focuses on optimization of each digestion phase i.e. Acidogenesis and Methanogenesis; enhancement of the overall digestion process and reduction of the detention time for anaerobic digestion.

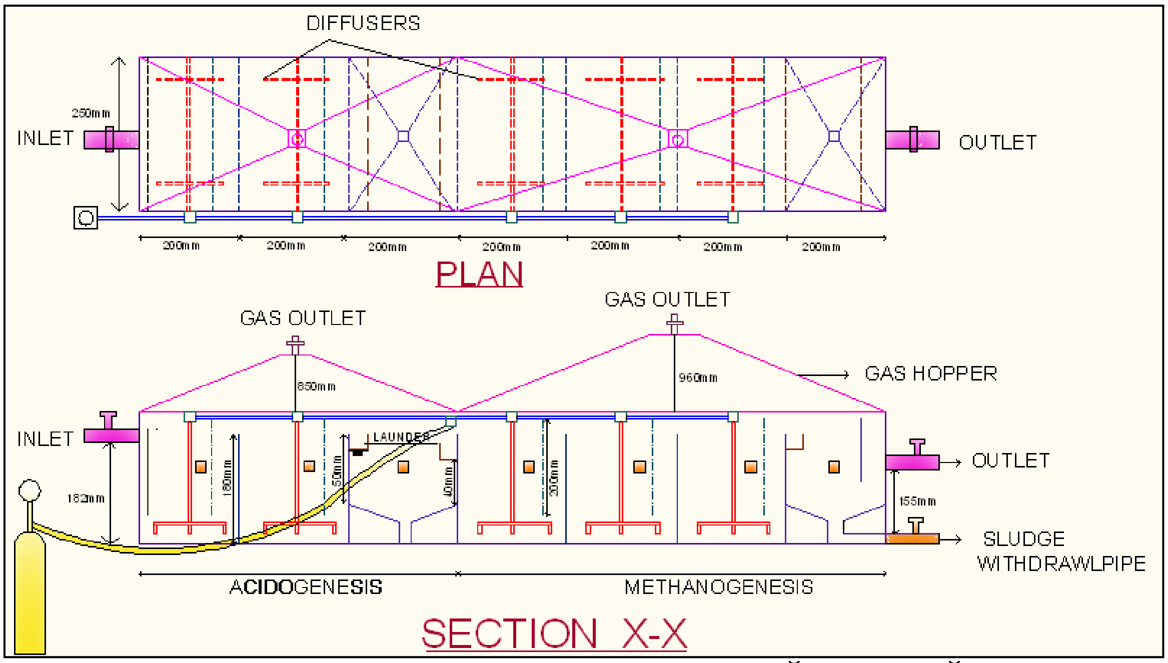
2. Materials and Methods

2.1 The lab scale model of pH based Bi-Phasic MB-HRAR

The laboratory scale model of pH based Biphasic MB-HRAR is made up of 8 mm thick acrylic sheet consisting of acidogenic and methanogenic compartments separated by a settling tank as shown in Figure No. 1. The acidogenic compartments consisted of 2 nos. of hanging baffles and 1 no. of standing baffle, while the methanogenic compartments consisted of 3 nos. of hanging baffles and 2 nos. of standing baffles. The wastewater flowed over and under the standing and hanging baffles respectively from the inlet to the outlet of the reactor. This type of arrangement thus had resulted into 2 and 3 compartmentalized configuration for acidogenesis and methanogenesis respectively.

Gas Mixing is provided in each compartment to facilitate the suspension of biomass improving the contact between micro-organisms and organic matter. The primary aim of providing the gas mixing is to recirculate the biogas produced in the reactor itself, so as to eliminate the cost of providing mechanical mixers. Firstly bottom diffusers were provided which were clogged as soon as mixing was stopped. Thus the gas mixing system was changed. Moreover, the nozzles were inclined at an angle of 45° which resulted into effective mixing. In the laboratory, as it is not possible to compress and recirculate the biogas produced, nitrogen gas is passed as a substitute. Gas mixing is provided for fifteen minutes for every two hours. The biogas is collected in a rectangular tank filled with water, where the downward displacement of water gives the volume of biogas generated.

After the acidogenesis and methanogenesis compartments a settling tank is provided for the biomass to settle, which was referred to as the Stagnant Acidogenesis and Stagnant Methanogenesis. The sludge withdrawn from the Stagnant Acidogenesis is recycled to the inlet and that from the Stagnant Methanogenesis is recycled to the first methanogenic compartment. The physical features are presented in Table No. 1



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Description of units	Value	
	Acidogenesis Unit	**Methanogenesis Unit**
Size: L x W x H	400mm x 200mm x 200mm	600mm x 200mm x 200mm
Overall height of reactor	250mm	250mm
Active Volume	16 L	24 L
No. of compartments	2	3
No. of standing baffles	1@ 200mm all along the length	2@ 200mm all along the length
No. of hanging baffles	2	3
Gas collection port	1	1
No. of sampling port	2 (one in each compartment)	3 (one in each compartment)
No. of washout valves	2 (one in each compartment)	3 (one in each compartment)
Size of gas mixing pipe i) Horizontal pipe ii) Vertical pipe iii) Nozzles	In each compartment: 3mm Ø, 200mm length 2 nos., 3mm Ø, 200mm length 8 nos. (4 in each vertical pipe)	In each compartment: 3mm Ø, 200mm length 2 nos., 3mm Ø, 200mm length 8 nos. (4 in each vertical pipe)
No. of Inlet valves	2	
No. of Outlet valves	2	
Settling Tank		
(a) No. of settling tank	2	
(b) Size of settling tank	200mm x 200mm x 40mm	

2.2 Analytical Procedure:

The performance of anaerobic treatment systems are affected by many factors ranging from process loading factors such as the SRT, OLR and HRT; to environmental factors such as temperature, pH, nutrient supply, and the presence of toxics; to operational factors such as mixing and characteristics of the waste being treated. Historically, the stability and performance of anaerobic treatment systems have been considered to be poor in comparison to aerobic systems. However, with improved understanding of the factors that affect their performance, it has been possible to obtain stable and reliable performance. Consequently, a thorough understanding of these factors is required for successful design and operation. [7]

The performance of the laboratory scale pH based Biphasic MB-HRAR is studied by using cow dung as the only substrate. Cow dung slurry is made in the ratio 1:3 (cow dung: water). The experimental procedure is presented in the following steps:

i) For preparing the substrate, one part of cow-dung is mixed with three parts of water. After sometime, settled slurry and floating materials is removed from the feed to prevent clogging at the inlet and outlet.
ii) Initially the reactor is completely filled with 1:3 cow dung slurry.
iii) After a period of 20-21 days, 2.3 L is fed (i.e. 1.15 L two times) daily.
iv) In the inlet the pH of the feed is reduced from 7.2 to 5.5 by adding mixture of sulphur based organic acid. The dosing of 7 ml/day is required.
v) After Acidogenesis i.e. HRT of 11days (i.e. 8days in acidogenic compartment and 3 days in the settling tank), the pH of the slurry is increased to 7.0 by adding lime solution. The dosing of 10 gm/day of lime is required.
vi) Gas mixing is provided at a rate of 0.01 $m^3/min/m^3$.Gas mixing is provided for 15 min at every two hours for acidogenesis and methanogenesis separately.
vii) The operating hours for the reactor is 8 hrs a day.
viii) The slurry from the stagnant acidogenesis is recirculated in the inlet (i.e. 10%) and the slurry from the outlet is recirculated in the first methanogenic compartment (i.e. 10%) along with lime dosing.
ix) In the methanogenesis compartment after HRT of 12 days, the outlet slurry characteristics are measured.

The operating parameters of performance evaluation are summarized in Table No. II

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Operating Parameters	Units	Values
OLR	gmCOD/ L.day	1.6 – 1.8
Temperature	°C	Max. = 31.4-46.8 °C (day) Min. = 23.9-31°C (night)
Inlet pH	-	5.5
Inlet COD	mg/L	35,000 – 40,000
Inlet Alkalinity	mg/L	6,400 – 7,200

The parameters such as alkalinity, pH, Chemical Oxygen Demand (COD) and Total solids (TS) are measured daily at inlet and outlet in order to check the performance of the reactor during study period as per the procedure mentioned in Standard Methods (1998).

2.3 Observations and Modifications

The following observations were taken and respective modifications were carried out for better performance of the reactor.

i) For cow dung slurry of ratio 1:3, the inlet and outlet were clogged. Thus inlet and outlet pipe diameter was increased from 1 cm to 2.5 cm.
ii) The launder design provided prevented the further flow, so the design of the launder was changed.
iii) Firstly bottom diffusers were provided which were clogged as soon as mixing was stopped. Thus the gas mixing system was changed. The former and later gas mixing systems is shown in Figure No. 2 and 3 respectively.
iv) Thick scum layer was formed in the settling tanks. Thus continuous withdrawal of sludge from the settling tanks was carried out so that proper flow takes place in the reactor. In other compartments the formation of scum layer was prevented due to proper mixing.
v) At the inlet the pH was reduced in the feed itself. pH control was difficult in the methanogenic compartments. Firstly lime dosing was carried out in the launder of the stagnant acidogenesis, and then it was carried out in the first methanogenic compartment.
vi) It was difficult to measure the actual amount of biogas produced as nitrogen gas was also passed.

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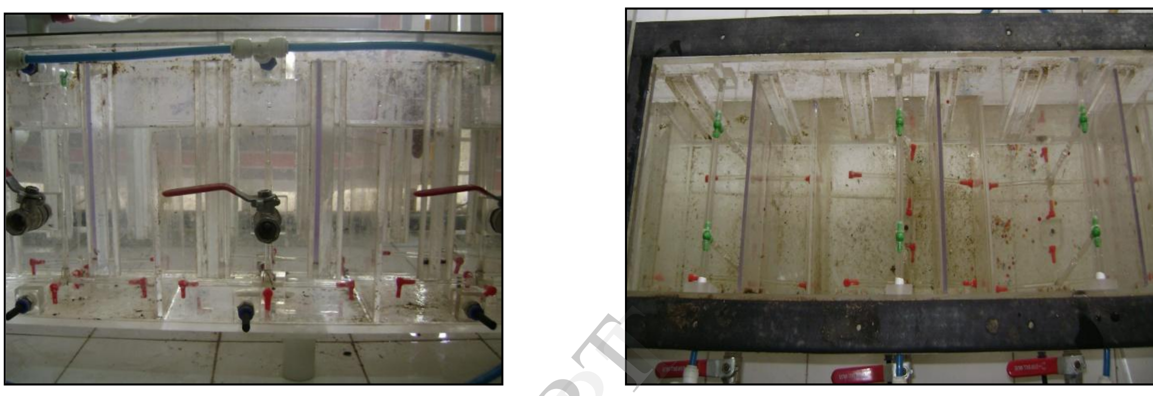

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3. Results And Discussions

To evaluate feasibility of pH based biphasic MB-HRAR, for generation of biogas using cow-dung, the reactor is operated at Hydraulic Retention Time (HRT) of 23 days and Organic Loading Rate (OLR) in the range of 1.6 – 1.8 gmCOD/L.day to observe the performance of the reactor in terms of % COD removal and % TS reduction. Throughout the study, the reactor is operated at top inlet and outlet. During the study, intermittent mixing of 15 min at every two hours is provided.

The biogas generation is calculated by subtracting the amount of nitrogen gas passed. The nitrogen gas is passed at a rate of 0.01 m^3/min/m^3 in each compartment. Mixing is provided five times a day for 15 minutes every two hours. Theoretically, biogas generation is also calculated based on the fact that 0.351 CH_4 is produced per gm COD converted at STP. [3]

The graphical representation of the pH based Biphasic MB-HRAR trends are shown in **Figure No. 4, Figure No. 5** and **Figure No. 6:**

It was difficult to measure the actual amount of biogas produced as nitrogen was also passed. Thus the biogas collection and measurement is needed to be modified and corrected, particularly the leakages.

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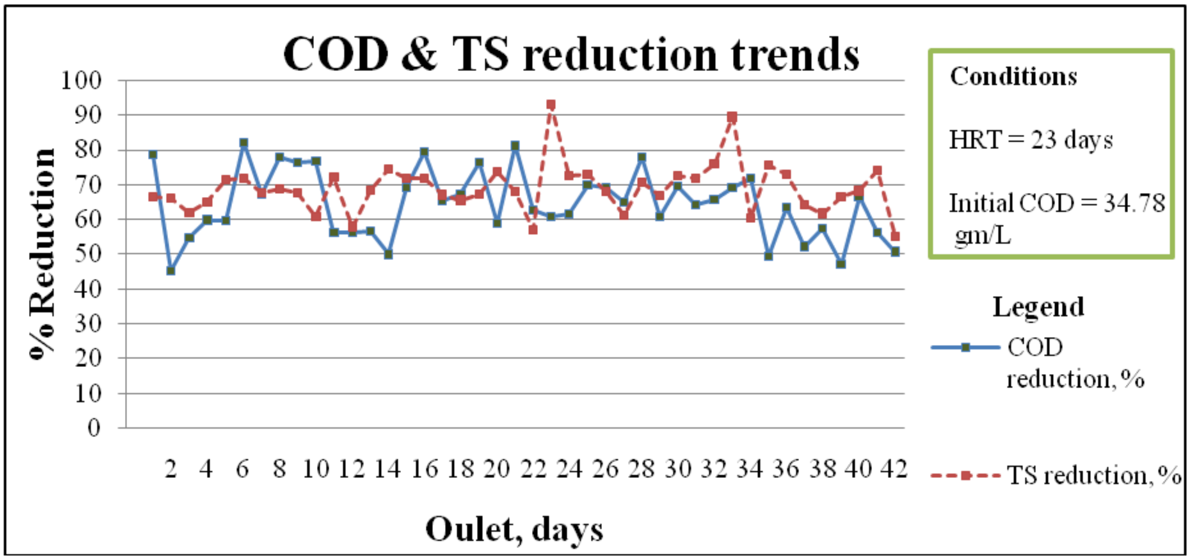

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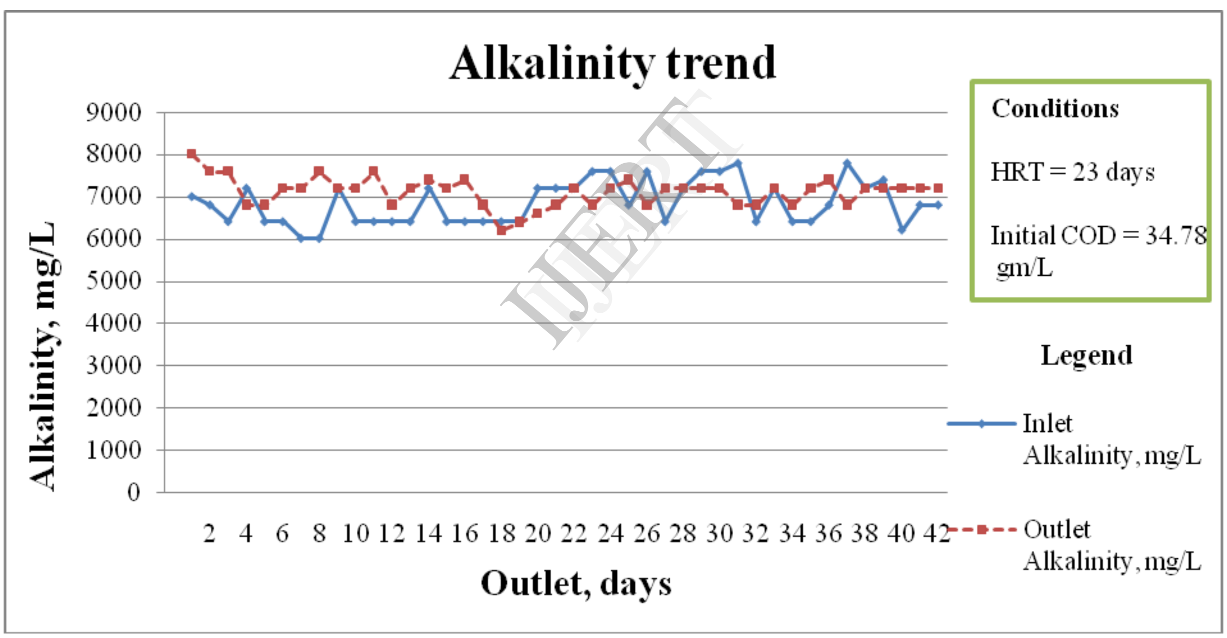

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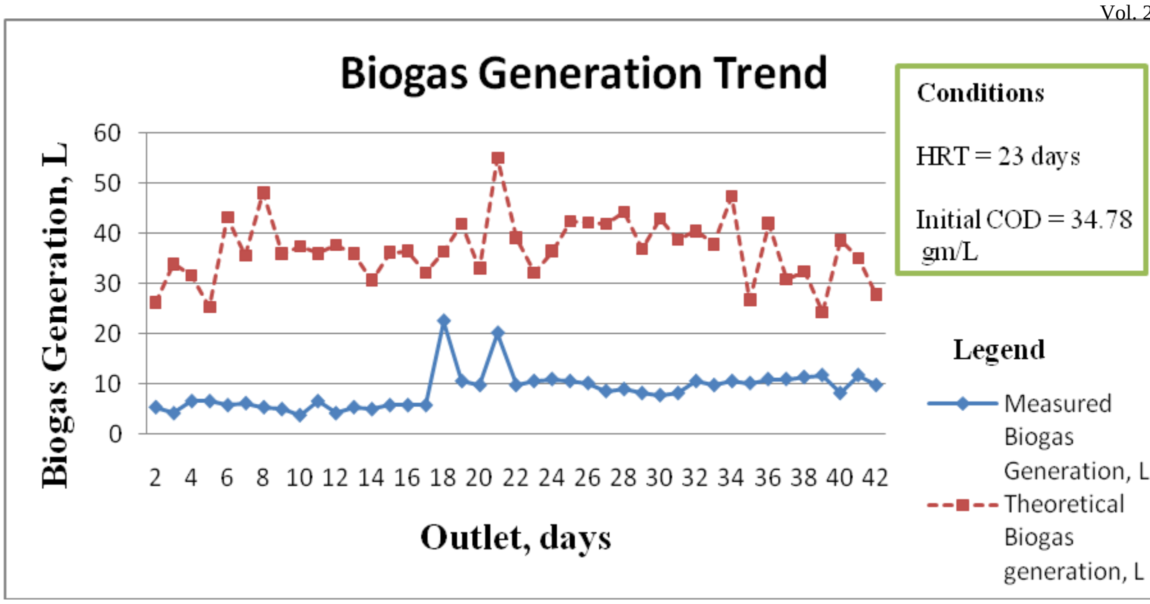

4. Conclusions

From the study the following conclusions were drawn:

i) Based on the results and discussions presented in the foregoing sections, at a HRT of 23 days, average COD reduction is 64.29% and average TS reduction is 69.01%.

ii) The temperature varied from maximum temperature range of 31.4-46.8°C during day time and minimum temperature range of 23.9-31°C during night time.

iii) The average initial alkalinity is 6843 mg/L and the average outlet alkalinity is 7115mg/L, thus showing an increase in alkalinity due to conversion of nitrogen to ammonia.

iv) The theoretical biogas generated is 76-77% more than the measured biogas. Biogas generated could not be collected and measured effectively as reflected by the measured quantity of gas which is one third of the theoretical values.

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