Computer Aided Analysis and Prototype Testing of an Improved Biogas Reactor for Biomass System

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ABSTRACT

The alternative fuel resources substituting for conventional fuels are required due to less availability of fuel resources than demand in the market. A large amount of crude oil and petroleum products are required to be imported in many countries over the world. Also the environmental pollution is another serious problem when use petroleum products. Biogas, with the composition of 54.5% CH_4, 39.5% CO_2, and 6% other elements (i.e., H_2, N_2, H_2S, and O_2), is a clear green fuel that can substitute the regular petroleum fuels to reduce the pollutant elements. The purification process can be further applied to take away the pollutants in biogas. The pure biogas process analyzed in this research is compressed to 2950 psi while being filled into gas cylinder. The daily produced biogas capacity is around 5480 ft^3 and the processing efficacy is affected by surrounding environment and other factors. The design and development of this biogas system is assisted through mathematical analysis, 3D modeling, computational simulation, and prototype testing. Both computer aided analysis and prototype testing show close results which validate the feasibility of this biogas system in biomass applications.

Keywords: Green resource, sustainable energy, biomass system, environmental protection, fuel efficacy, cost effective, biogas enrichment.

INTRODUCTION

Biomass, the biological materials, can be produced by processing some surviving or lately deceased organisms including crops or materials relevant to crops. Biomass is considered as one type of energy resource that can be applied to generate heat by direct combustion or can be changed to other types of biofuel by some technologies. The biomass can be changed to bio-fuel by alternative ways including biochemical, chemical, and thermal methodologies. The current common fuels used in commercial transportation systems are petrol or diesel and its demand is increasing sharply due to modern industrialization. Because of the shortage in natural petroleum supply, a lot of petrol-related products have to be imported from outside of country. Although the natural gas has methane, ethane, propane, butane and other elements, biogas posses 68-78% enriched methane. Pure methane can be potentially produced from biogas by using scrubber. Because enriched methane can be easily bottle-compressed after being produced from biogas, it can be potentially used as gas fuel for many different applications. Some organic wastes including commercial/residential wastes, sewage waste, and community solid waste can be used as source stocks to make biogas. Biogas is one of the green, sustainable and clean fuels and the wastes generated during biogas production can be utilized for making fertilizer products. The common source materials to produce biogas are usually biodegradable wastes existed in many commercial/residential areas including wastes from human, paper, food, and many other organic materials.

COMPUTER AIDED MODELING AND SIMULATION

This biogas enrichment system is shown in Fig. 1.

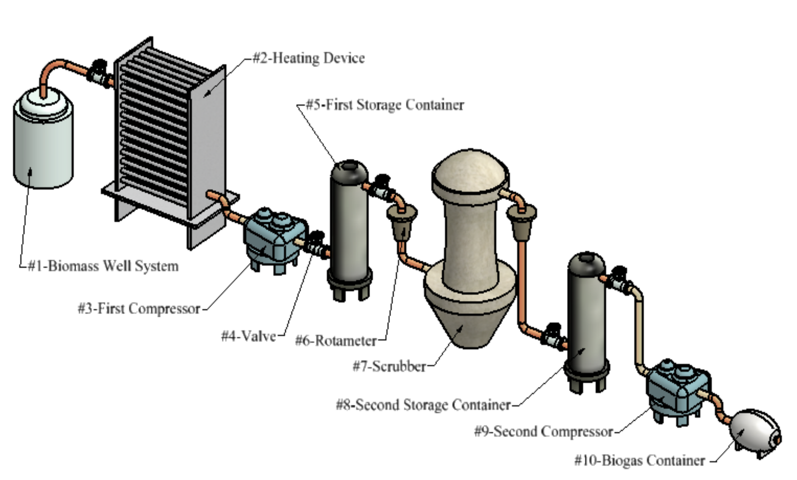

Fig. 1 Biogas enrichment system

The computational simulation has been performed to study and modify the performance of biogas reactor in biomass system. In biogas reactor unit, the external force is used to drive the rotation of biomass mixer to produce the biogas. The heating energy needed for digester and heating energy lost in system require to be considered. The normal temperature in digester for heating biogas plant changes from 24.5˚C to 38.5˚C and heating energy required in the digester depends on environmental conditions including surrounding temperature. The heating energy needed in digester can be specified by following equation (1).

$$Q_{REQ} = (C_P * M * \Delta T_{REQ} * t) + Q_{LOSS} \quad (1)$$

The heat loss through digester surface can be found from equation (2).

$$Q_{LOSS} = S * C_H * \Delta T_{LOSS} * t \quad (2)$$

The raw feeding materials, driven by reactor blades, rotate rapidly to continuously produce biogas inside biogas reactor. To improve biogas reactor design, three different blade structures shown in Figs. 2 - 4 are analyzed.

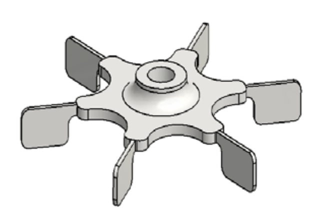

Fig. 2 Bio-blade 1

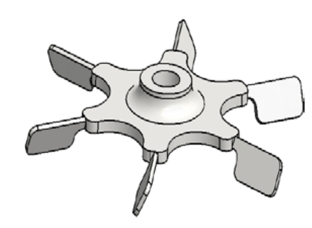

Fig. 3 Bio-blade 2

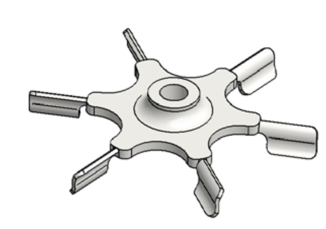

Fig. 4 Bio-blade 3

The Figs. 2 – 4 display that the bioreactors 1, 2, and 3 consist of vertical straight blades, inclined straight blades, and inclined curved blades respectively.

The 3-D modeling of three different reactor blades and its relevant computational simulations have been performed to potentially improve functionality of biogas reactor system. The simulation results of stress profiles and deformation profiles of these three bioreactors are presented in Figs. 5 – 10.

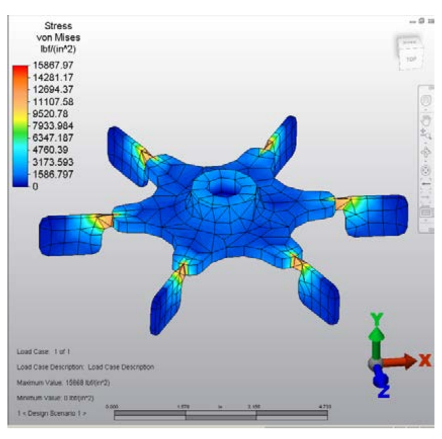

Fig.5 Stress in blade 1

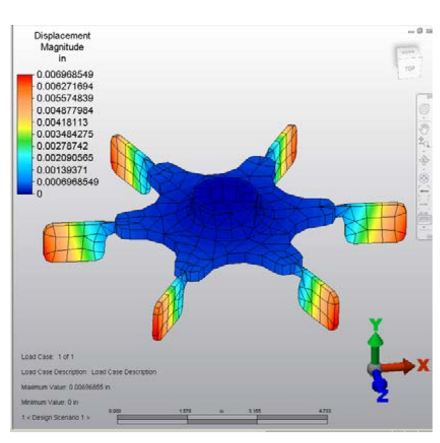

Fig.6 Deformation in blade 1

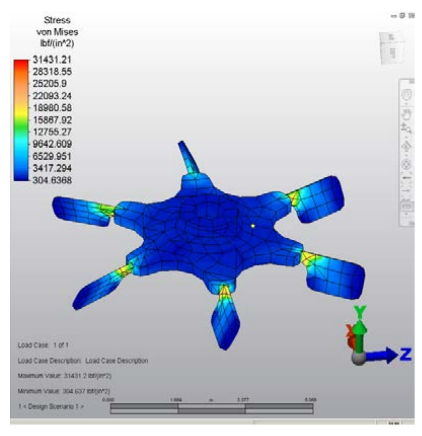

Fig.7 Stress in blade 2

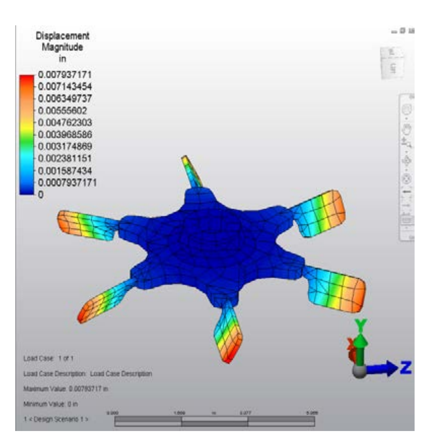

Fig.8 Deformation in blade 2

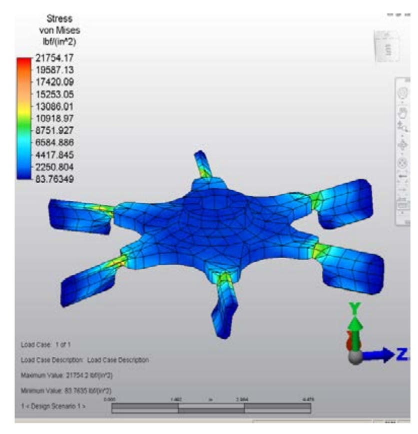

Fig.9 Stress in blade 3

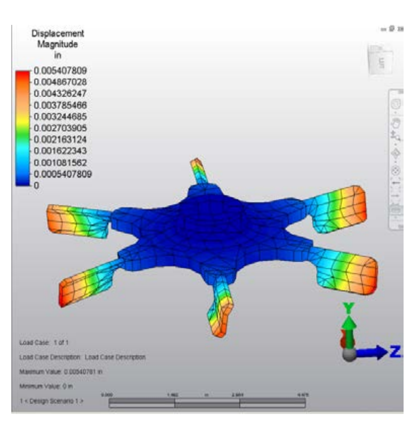

Fig.10 Deformation in blade 3

Based on simulation results in Figs. 5 – 10, the maximum stress of 15867.97 psi in blade 1 is less than 21754.17 psi in blade 2 and 31431.21 psi in blade 2. The results show that the vertical straight blades has less stress produced in blade root areas compared to other two blades due to its geometrical shape and less force required to rotate reactor blades. Since the yield strength of mild steel is 36300 psi, the blade 1 design in biogas reactor can function appropriately with safety factor more than 2 and the maximum deformation in blade 1 is within the material allowable limit. Since the blade 2 and 3 designs have safety factors 1.15 and 1.67 respectively, these two blades require further modification and improvement.

PROTOTYPE EXPERIMENT

The biogas reactor has been prototyped and experiment has been performed to justify the design concept and confirm computational simulation. Tables 1, 2, and 3 display the experimental results of stress and deformation profiles in three different blades.

Table 1 Experiment of stress and deformation in blade 1

Number of Test	Blade 1	
	Stress (N/mm^2)	Displace (mm)
1	15867.92	0.00699
2	15867.99	0.00698
3	15867.84	0.00688
4	15867.78	0.00665
5	15867.98	0.00659
6	15867.48	0.00648
7	15867.68	0.00638
8	15867.75	0.00657
9	15867.65	0.00654
10	15867.84	0.00666
Average	15867.79	0.00667

Table 2 Experiment of stress and deformation in blade 2

Number of Test	Blade 2	
	Stress (N/mm^2)	Displace (mm)
1	31431.54	0.00799
2	31431.29	0.00788
3	31431.18	0.00778
4	31431.24	0.00754
5	31431.38	0.00766
6	31431.48	0.00778
7	31431.15	0.00799
8	31431.48	0.00786
9	31431.54	0.00788
10	31431.39	0.00785
Average	31431.37	0.00782

Table 3 Experiment of stress and deformation in blade 3

Number of Test	Blade 3	
	Stress (N/mm^2)	Displace (mm)
1	21754.25	0.00529
2	21754.15	0.00548
3	21754.24	0.00538
4	21754.35	0.00524
5	21754.48	0.00518
6	21754.38	0.00522
7	21754.54	0.00512
8	21754.12	0.00518
9	21754.18	0.00524
10	21754.24	0.00525
Average	21754.29	0.00526

The average maximum stress and deformation in Table 1 are 15867.79 psi and 0.00667 inches for blade 1 that are almost equal to 15867.97 psi and 0.00697 inches determined by computational simulation. The average maximum stress and deformation in Table 2 are 31431.37 psi and 0.00782 inches for blade 2 that are approximately same as 31754.17 psi and 0.00794 inches specified by computational simulation. The average maximum stress and deformation in Table 3 are 21754.29 psi and 0.00526 inches for blade 3 that are very close to 21754.17 psi and 0.00541inches found by computational simulation. Both computational simulation and prototype testing show proper function of biogas reactor and validate the feasibility of analytic methodology applied in this research.

CONCLUSION

Biogas is a green/clean fuel resource that can be potentially used in many different applications. This sustainable energy resource, an alternative to the current conventional energy market, can be used to protect environment. The byproduct from biogas production can be potentially used for agricultural fertilizer and some production processes. Both computational simulation and prototype experiment on this biogas reactor are introduced to study and analyze this biogas reactor design for turther improvement. Both computational simulation and prototype experiment on three different reactor blades affirm that the vertical straight blade geometry in biogas reactor provides better performance than other two blade geometries.