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Computational Fluid Dynamics Based Verification Of Mixing In An Operating Sewage Sludge Anaerobic Digester

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ABSTRACT

It is estimated that in the next coming few years, the volume of sewage will be 14000 million liters per day in India. All this sewage has to be treated and implies treatment by aerobic biological processes with inbuilt biomethanation and electrical energy generation by gas engines to meet the operation and Maintenance costs of electricity. The crucial role of anaerobic sludge digesters becomes paramount. Presently, there are only thumb rules for designing the configuration of digesters and deciding the power needed to mix their contents. The present work is taken up in this context and has verified the design parameters for optimizing the configuration of inlet and outlet piping coordinated with respect to mixing energy dissipation in the digester by using the computational fluid dynamics (CFD) approach on a functioning digester. The traditional approach of a single point inlet near the floor for feed sludge and another inlet near the sewage level for recirculation appears flawed and multiple inlets of blended sludge of feed and recirculation are needed for meeting the mixing needs. Numerous simulations have been carried out on various configurations of inlet height, tank diameter and pipe diameter (with varying velocity) and observed that change in pipe diameter has the maximum influence on the active region compared to the other parameters.

Keywords: Anaerobic digestion (AD); Mathematical model; Biomethanation; Sonication; Total solids; Computational Fluid Dynamics (CFD)

1. INTRODUCTION

Economy, energy and ecology are interrelated and must go hand in hand to ensure a sustainable prosperity of human beings. Technological innovations are continuously improving the quality of human life, which necessarily demand additional energy inputs at every stage of improvement. This ever-increasing energy demand is mostly met through consumption of non-renewable commercial fuels resulting in irreversible adverse impacts on the environment coupled with depletion of natural reserves of commercial fuels. The Indian economy mostly relies on expensive imports of commercial fuels for industrial and urban needs, and forestry biomass for rural communities. This necessitates development of innovative technologies for exploitation of renewable energy sources to compensate the energy balance. A number of attempts are being made to harness the renewable sources of energy such as solar, wind, tidal, hydropower. Biomethanation technology (BT) may be perceived as a potential alternative as it not only provides renewable source of energy but also utilizes recycling potential of degradable organic portion of solid waste generated by a numerous activities in the country. Anaerobic digestion is gaining wider acceptance in the present scenario over aerobic treatment due to production of biogas, which can be further used for meeting a part of energy demand. BT is the anaerobic digestion of biodegradable organic waste in an enclosed space under controlled conditions of temperature, moisture, pH, etc. It is a human engineered decomposing system wherein depending on the waste characteristics, the waste mass undergoes decomposition anaerobically thereby generating biogas comprising mainly methane and carbon dioxide.

In the present scenario, the reduced organic and inorganic compounds produced by anaerobic microbial processes serve as carbon and energy reservoirs for photosynthetically fixed energy. When the later is exposed to aerobic conditions; the compounds serve as substrate for aerobic chemolithotrophs and heterotrophs. Accordingly, two life styles are intimately coupled and function together for mutual benefit. A variety of waste sources like urban, agriculture, industrial sectors, vegetable markets, etc. generate huge quantities of solidwaste containing a sizeable proportion of biodegradable organic matter with Municipal SolidWaste (MSW) having largest proportion. Various parameters responsible for technical feasibility of the process of setting up a biomethanation plant in India is shown in Fig. 1 (Ambulkar and Shekdar, 2004).

Sewage sludge digesters and, indeed, other organic waste digesters, are tanks with minimal internal fittings, in which feedstock (e.g. sewage sludge, agricultural slurry, food waste) is maintained at constant temperature, mixed with anaerobic bacteria and reduced to a methane-rich biogas. Mixing energy is thought to account for approximately 20% of the total energy input of digesters in temperate climates; the remainder being used for sludge heating where required. The primary aim of mixing is to ensure physical, chemical and biological uniformity in a digester and to minimise grit deposition.

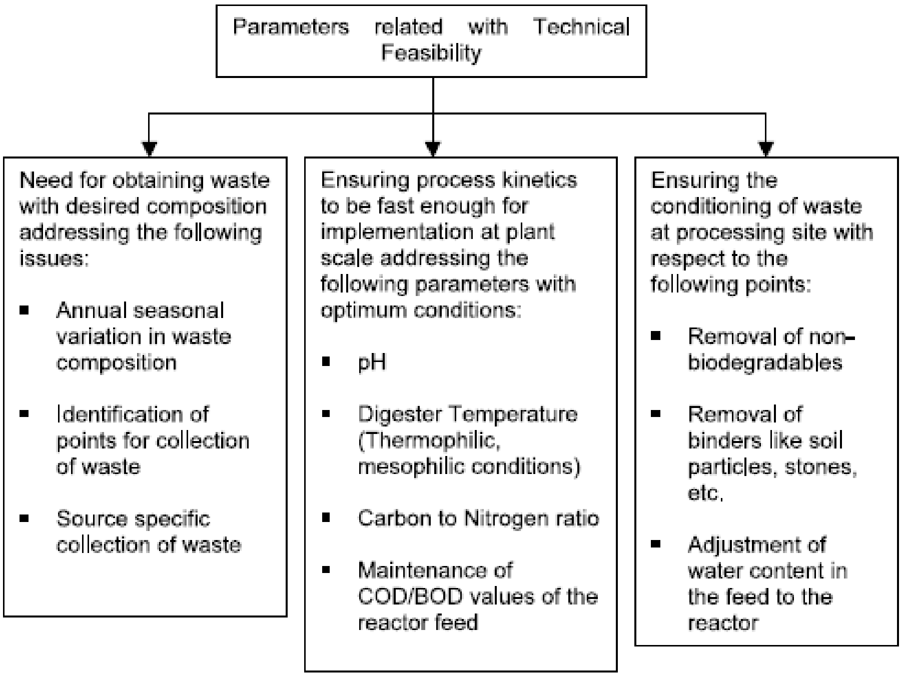

Fig. 1. Parameters responsible for technical feasibility of biomethanation plant (Ambulkar and Shekdar, 2004)

On the basis of primary and secondary data, the energy potential by the anaerobic digestion of the effluent from some of the polluting industries were estimated by Lata et al. (2002) and the pulp and paper industry was found to have the maximum potential. Authors were outlined the nature of wastewater generated by each sector, status of technologies for that sector in India and policy measures, which should be adopted for their large-scale adoption. Ambulkar and Shekdar (2004) discussed the technical feasibility, operational stability and commercial viability of Biomethanation technology (BT) in India. Various potential merits of BT like reduction in land requirement for disposal, preservation of environmental quality, etc. were also reviewed. A comparative study of researches related to the performance of various anaerobic digesters in different developed countries was carried out wherein various fractions of municipal solid waste (MSW) were utilized. Kashyap et al. (2003) reviewed psychrophilic anaerobic digestion studies reported by various researchers using different substrates. The effect of operational parameters such as type of substrate, size of inoculum, concentration of volatile fatty acids, hydraulic retention time and loading rate, on reduction of TS/VS, BOD/COD and biogas yield was also reviewed. Bridgeman et al. (2010) used the commercially-available CFD code, Fluent v6 to model the flow field within flocculators at both laboratory and full scale. The focus of the work concentrated on the development and application of simulation techniques and the analysis of computational models to increase understanding of floc formation and breakage mechanisms. Bridgeman et al. (2012) developed a computational fluid dynamics (CFD) model to simulate the mechanical mixing of sewage sludge at laboratory scale is reported. From the study, conclusions regarding velocity gradients and biogas yield were drawn.

Computational fluid dynamics (CFD) is an accepted and well used means of assessing and optimising process designs without necessarily incurring the expense of prototype development. Recent years have seen an increase in the application of CFD to water industry issues. However, the use of CFD to model the flow and mixing of organic wastes (such as manure) and sewage sludge has been rather more limited [2–7].

The present work focuses on verification of the design parameters for optimizing the configuration of inlet and outlet piping co-ordinated with respect to mixing energy dissipation in the digester by using the computational fluid dynamics (CFD) approach on a functioning digester.

2. Indian Scenario and Statement of the Problem

As of 2011, only 33 % of the 390 million urban Indian population had access to sewers. The Millennium Development Goals (MDGs) signed by India calls for meeting at least 50 % of urban sewerage by 2015. At a 2015 population of 440 million, the backlog will be close to (440*0.5)-(390*0.33) = 90 million. Even if 2015 is recast to say, 2020, this backlog will become close to 140 million by then. At a water use of at least 100 liters per capita per day, the volume of sewage will be 14000 million liters per day (MLD). All this sewage has also to be treated and implies treatment by aerobic biological processes with inbuilt biomethanation and electrical energy generation by gas engines to meet the O&M costs of electricity. As of now, the Central Pollution Control Board of India has observed that non-availability of electrical power in the local grid as well as inability of local bodies to pay for electricity are the main reasons for the vast number of sewage treatment plants being not consistent. Thus, the crucial role of anaerobic sludge digesters becomes paramount. Presently, there are only thumb rules for designing the configuration of digesters and deciding the power needed to mix their contents. The present work is taken up in this context and has verified the design parameters for optimizing the configuration of inlet and outlet piping co-ordinated with respect to mixing energy dissipation in the digester by using the computational fluid dynamics (CFD) approach on a functioning digester at a Chennai metropolitan area sewage treatment plant (STP). The traditional approach of a single point inlet near the floor for feed sludge and another inlet near the sewage level for recirculation appears flawed and multiple inlets of blended sludge of feed and recirculation are needed for meeting the mixing needs.

The High Power Expert Committee on Infrastructure of Government of India which has forecast an investment of Rupees 2426880 million between 2012 and 2031 for sewerage in India of which the investment needed for STPs will accrue at Rupees nearly 800000 million. Even if it is met, it is the imbalance of meager revenues to meet the break even expenditures of local authorities which will continue to render these STPs as non operational. In as much as nearly all costs of O&M lie in electrical energy in STPs, it is necessary to optimize the digester configuration for increased mixing to accelerate the biomethanation and electrical energy production.

The significance of this study can be realized when we realize the aforesaid prospects.

3. CFD Modelling

The Chosen Digester

This is part of an activated sludge STP at Chennai. The digester is typical of all other such digesters built in India and is 31.5 m diameter and 10 m vertical height of which 9.5 m is the sludge depth. The floor is a hopper of 3.75 m depth. Mixing is provided by pump sets drawing sludge from the bottom hopper and pumping into the digester at 9 m of the vertical 10 m height. Feed sludge is pumped in at 1.5 from the top of the hopper. The velocities through these inlet pipes are 0.5 m/sec.

The line diagram is depicted in Fig.2.

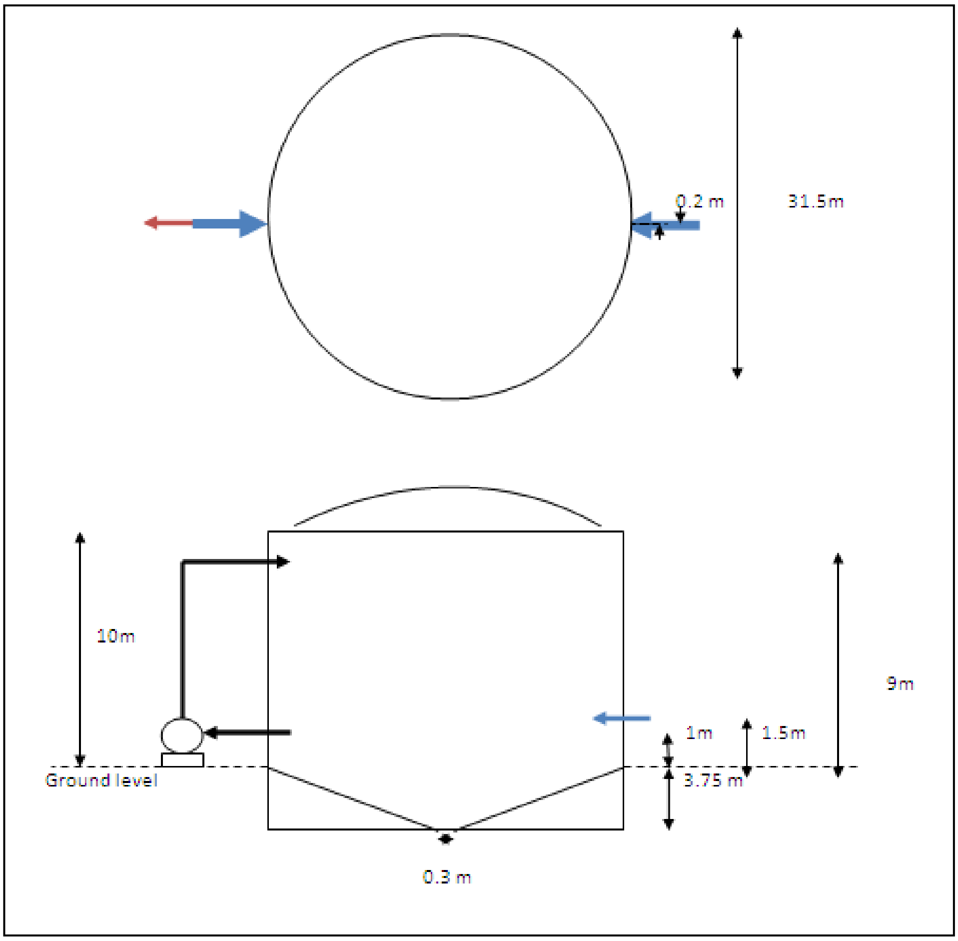

Figure 2. Inlet, outlet and recirculation locations in the Study Digester

The CFD Modeling

Computational Fluid Dynamics (CFD) modeling involves an input of the physical system and the software simulations involve solving the Navier Stokes and the continuity equations with the corresponding boundary conditions numerically by using algorithms. The solution requires the simultaneous CFD solution of the discredited mass, momentum, and energy equations. The existing configuration and proposed configurations were evaluated by using CFD simulation GAMBIT and FLUENT software by treating the sludge as the water instead of the non Newtonian fluid.

Flow domain and boundary conditions

No-slip boundary conditions were imposed on all wall surfaces. At the inlet a constant flow rate was specified, and the outlet was treated as a mass flow boundary. The commercial CFD code Fluent, version 6.3, developed by Fluent/ANSYS was used for all calculations. The code uses a finite volume method based on discretization of the governing differential equations.

Turbulence model

The standard k–ε turbulence model was used for all calculations with standard wall function approximations near walls; hence, additional transport equations for turbulent kinetic energy (k) and eddy dissipation (3) were solved for these quantities. The standard k– ε model has been successfully used by many researchers for similar mixing problems (Littleton et al., 2007a,b; Wasewar and Sarathi, 2008).

Solver

A 3D, implicit, pressure-based, segregated, steady solver algorithm was used for predicting the velocity and turbulence fields, and a time dependent mode was used for predicting sludge concentrations. The SIMPLE pressure–velocity coupling method was specified, and second-order upwind discretization molecules were used for all discretized terms.

CFD of Existing and Optimized Digester Configuration

The pattern is shown in Figure.2. It needs to be seen that there is very little mixing taking place. Hence, it was decided to evaluate various configurations. A summary of the results is presented in Table.1. The optimized configuration is shown in Figure 3 and the CFD typical pattern is shown in Figure 4.

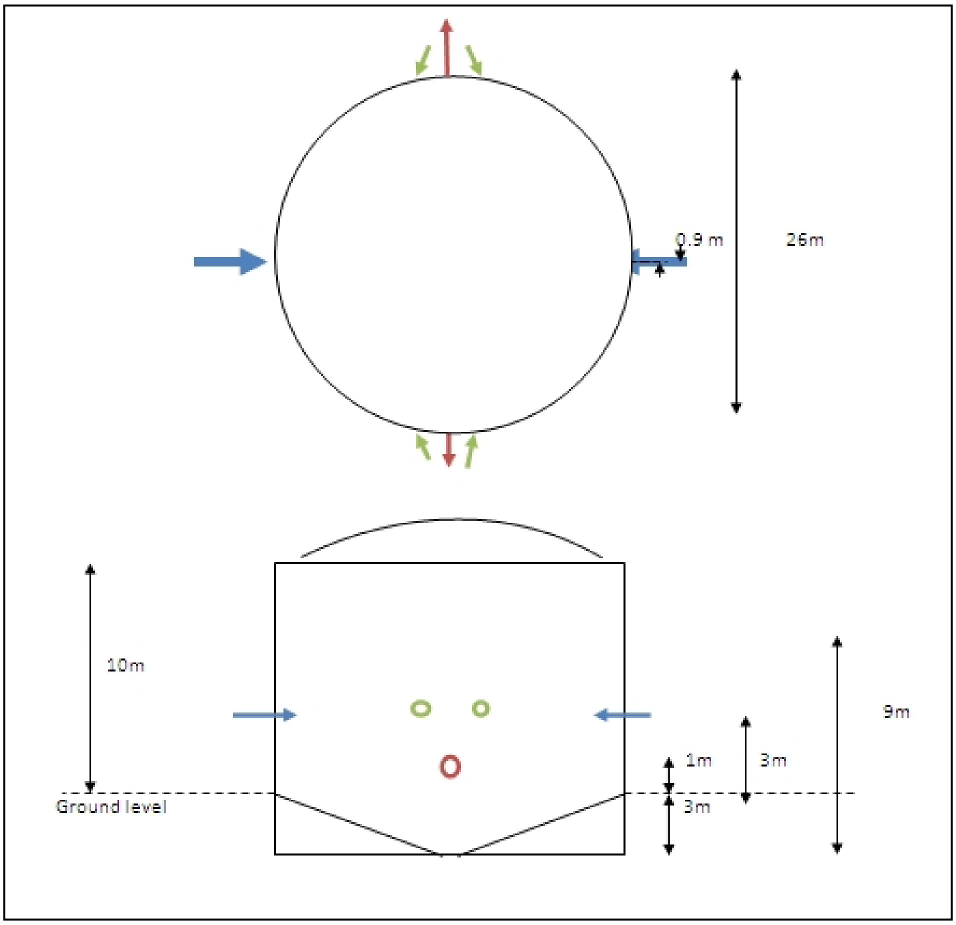

Figure 3. Optimized Configuration of Inlet and Outlet for the Study Digester.

Table. 1. Results of CFD Modelling of Existing and Proposed Configurations

S No	Diameter (m)	Inlet height (m) from ground level	Central tube	Pipe diameter (m)	Inlet Velocity (m/s)	Active region (%)
Existing Digester Configuration						
0	31.5	1.5	No	0.2	0.5	0.13
Studied Digester Configurations						
1a	30	3	Yes	0.8	1.5	45.8
1b			No			40.8
2a	30	3.5	Yes	0.8	1.5	57.9
2b			No			51.3
3a	30	4	Yes	0.8	1.5	56.3
3b			No			57.7
4a	30	4.5	Yes	0.8	1.5	58.0
4b			No			59.5
5a	26	3	Yes	0.8	1.5	51.5

5b			No			53.6
6a	28	3	Yes	0.8	1.5	41.7
6b			No			52.5
7a	30	3	Yes	0.8	1.5	45.8
7b			No			40.8
8a	32	3	Yes	0.8	1.5	39.3
8b			No			36.5
9	26	3	No	0.5	1.5	27.6
10	26	3	No	0.6	1.5	30.1
11	26	3	No	0.8	1.5	53.6
12	26	3	No	0.9	1.5	61.2
13	26	3	No	0.9	1.35	52.7
14	26	3	No	0.9	1.25	46.1

It needs to be seen that the active region in the existing digester is almost negligible and what appears to be happening inside the digester is more of a diffusion and displacement than mixing. The importance of mixing can be appreciated from the fact that mixing is needed to shear the cell walls of microbes by a phenomenon referred to as lysis and release the contents into the aqueous medium to undergo anaerobic digestion and produce methane gas. In the existing digester, though mixing appears practically nonexistent, still the lysis seems to occur by the prolonged hydraulic retention running to 15 days based on inlet feed flow. Logically, this may not be really the need of cell lysis can be brought about in lesser time which will reduce the volumes and costs of these digesters. This appears to be achieved in models 4b and 12.

Inferences

1. The investment cost of close to Rupees 8 billion for sewering the urban population of India is by itself a major challenge to resource and deploy
2. Even if this is somehow achieved, the need for incorporation of biomethanation and electrical energy recovery is imminent considering that most of the STPs are dormant due to paucity of funds for O&M which is almost directly the electrical energy costs
3. The crucial issue here resides in the need to find out and decipher the anaerobic digester configuration to reduce the construction costs of these high volume digesters
4. It reveals that the existing configuration and deployment of mixing energy in the study digester is uneconomical vis avis the investment made.
5. It is revealed that the active mix region is hardly 0.13 % based on the volume mixed and rather negligible compared to nearly a 60% volume mixed in the optimized configuration.
6. This must be correlated to the possibility of a drastic reduction of the hydraulic retention time of the digester and in fact accelerated methane yield.

7. Further studies are planned in physical modelling of the above in actual field scale by a control based on existing configuration and a model based on the study findings.

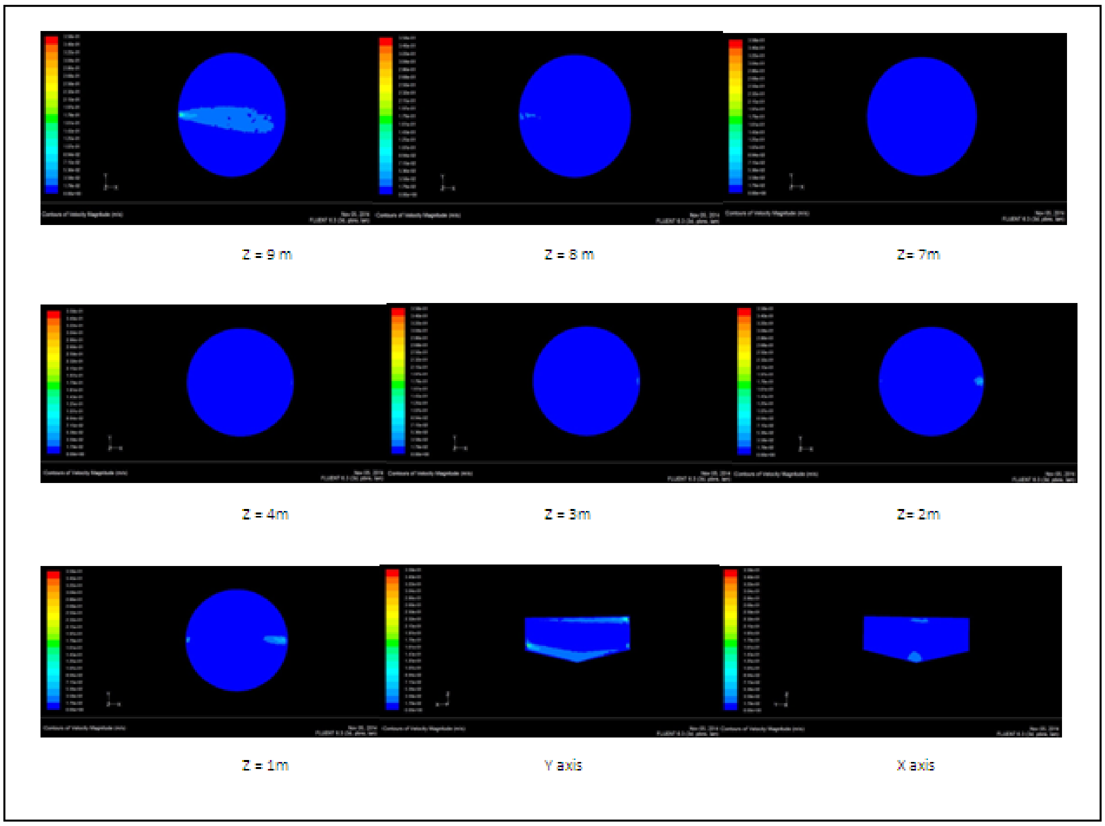

Figure 4. CFD Results for the Existing Digester configuration (Number 0 in Table-1)

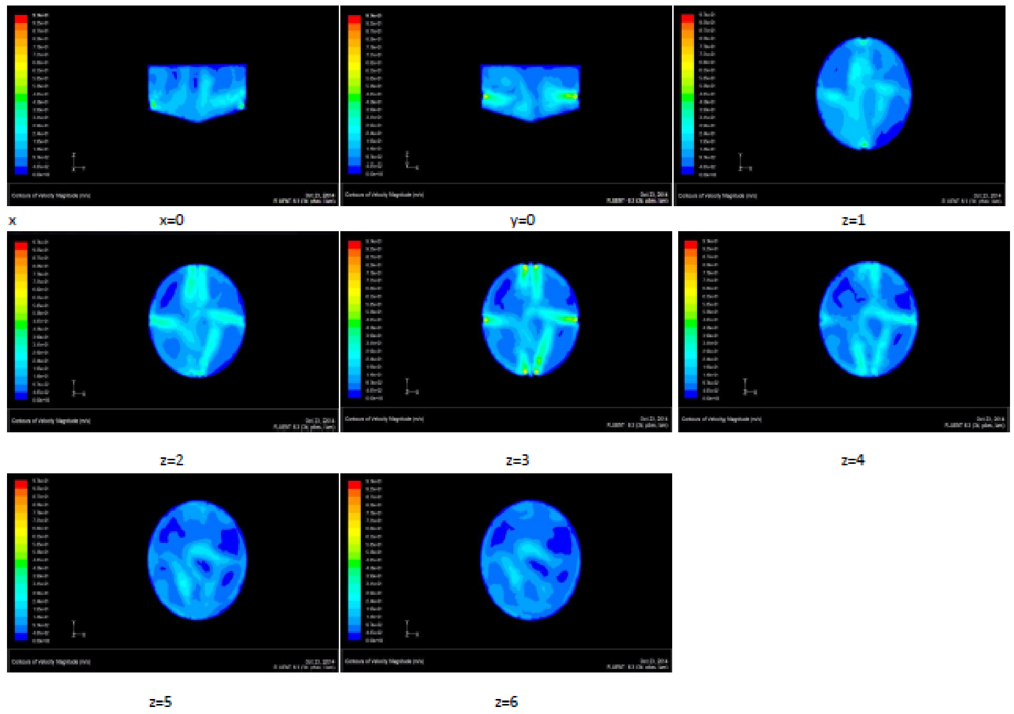

Figure 4. CFD Results for the Optimized Digester configuration (Number 12 of Table-1)

4. Conclusions

Computational fluid dynamics (CFD) modelling and analysis has been performed for optimizing the configuration of inlet and outlet piping coordinated with respect to mixing energy dissipation in the digester for effective functioning. Numerous simulations have been carried out on various configurations of inlet height, tank diameter and pipe diameter (with varying velocity) and observed that change in pipe diameter has the maximum influence on the active region compared to the other parameters. It was further noted that the traditional approach of a single point inlet near the floor for feed sludge and another inlet near the sewage level for recirculation appears flawed and multiple inlets of blended sludge of feed and recirculation are needed for meeting the mixing needs.

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