

# Steady State Simulation of Plastic Pyrolysis Process using Aspen Hysys V9 Simulator

Selvaganapathy.T, Muthuvelayudham R, Jeya Kumar M.

**Abstract:** The present study was carrying out the simulation of plastic pyrolysis process modelled for the conversion of petroleum product from plastic wastes such as Poly-Styrene (PS), Poly-Ethylene (PE), Poly-Propylene (PP) and Poly-Styrene (PS) with the aid of Aspen Hysys V9 simulator. Aspen Hysys simulator was used to develop the steady state model and to simulate the pyrolysis process with the above mentioned plastic wastes. Peng-Robinson thermodynamics model was employed as a fluid package of this simulation. The process converts waste plastic to fuel, which was taking places in two stages in an Aspen Hysys Simulation Environment such as i) A conversion of plastic wastes into Vapour-Liquid Fraction (VLF) with small quantity of char residue using conversion reactor (Pyrolytic Reactor) and ii) Separation of produced Vapour-Liquid Fraction to pyro gases and liquid fuel with the help of water tube Condenser. The obtained results demonstrated that, a conversion of Poly-Styrene (PS) into liquid fuel is up to 88.7% was optimum than other plastics Poly-Ethylene (PE) 81.95% and Poly-Propylene (PP) 83.54 %. The simulated model can help an interested to researcher in knowing expected products and their individual component for better understanding and scale-up studies.

**Keywords:** Aspen Hysys V9simulator, Peng-Robinson, Pyrolysis process, Steady state model

## I. INTRODUCTION

Plastic products have now become an integral part in our day by day life as an essential need and the demand is expanding due to their high adaptability, moderately ease and attractive applications in agriculture [1], households [2], automobiles [3], packing materials [4], and variety of their other applications [5]. Mostly, thermoplastics polymers make up a high proportion of waste, and their generation has consistently expanded around the worldwide. It delivered on a monstrous scale worldwide and its generation crosses the 150 million tons for consistently comprehensive. In India approximately 8.33 Metric tons of plastic items are consumed every year. Considering, 70% of plastic utilization is changed over as waste, approximately 5.6 million tons per annum (TPA) plastic waste is produced in India, which equivalent to 15342 tons per day (TPD). According to the Central Pollution Control Board (CPCB) survey, plastic contributes to 8% of the total solid waste, with Delhi delivering the maximum quantity followed by Kolkata and Ahmedabad [6].

Revised Manuscript Received on November 15, 2019

\* Correspondence Author

Selvaganapathy T\*, Assistant Engineer, Tamilnadu, Pollution Control Board, Tamilnadu, India [Email: selvachemengg@gmail.com](mailto:selvachemengg@gmail.com)  
Muthuvelayudham R, Professor, Annamalai University, Chidambaram, Tamilnadu India, [Email: muthupriya.03@gmail.com](mailto:muthupriya.03@gmail.com)

Jeya Kumar M, principal (In-charge), Sri Ramana maharishi college of Engineering, Tamilnadu India, [Email: drjkiothu@gmail.com](mailto:drjkiothu@gmail.com)

Plastic solid wastes consist of polyethylene, polypropylene, polystyrene, vinyl, and polyethylene terephthalate [7]. Overall, about 50-70% of the total plastic waste is packaging materials derived from polyethylene, polypropylene, polystyrene, and polyvinyl chloride [8]. On average, polyethylene makes up the greatest fraction of all plastic wastes (69%), especially plastic bags and polyethylene comprises 63% of the total packaging waste [8]. Hence, plastic solid waste become a very critical environmental issue because of their huge quantity and disposal problem as thermoplastic do not bio-degrade for quite a while.

Recycling is the best possible way/solution for environment, there are categorized into primary (re-extrusion), secondary (mechanical recycling), tertiary (chemical recycling) and quaternary recycling (incineration- restricted in India). Chemical recycling method also termed as pyrolysis is one of the most efficient and effective method of recycling of plastics simultaneously it converts waste plastic into fuel. Most of the recycling processes are expensive, energy intensive and end up producing low-grade products. Pyrolysis is a sustainable waste management process and Eco-Friendly approach to treat plastic solid waste containing carbonaceous materials like plastics and biomass [9]. Pyrolysis also termed thermolysis derived from Greek (pur = fire; thermos = warm; luo = loosen) is a process which thermally breaks down higher molecular carbonaceous compound to produce lower molecular compounds in an oxygen-devoid environment at considerably high temperature [10]. The products of pyrolysis are condensable gases, char residue and non-condensable gases. The vapour consists of condensable gases that transform into liquid (pyrolytic fuel) after condensation while the non-condensable are collected or vented as gases [11]. Pyrolysis can be conducted at various variables temperature levels, reaction times, pressures, and in the presence or absence of catalysts. Plastics pyrolysis proceeds at low temperature (<400°C), medium temperature (400–600°C) or high temperature (>600°C) [12]. However the optimum temperature range (450°C) was predicted in our previous paper [13].

The purpose of steady state simulation is to imitate the performance of any chemical process. The process characteristics (e.g. flow rates, compositions, temperatures, pressures, properties, equipment sizes, etc.) are anticipated using analysis techniques. These techniques include mathematical models, empirical correlations and computer-

aided process simulation tools (like Aspen Hysys). It is a computer-aided software which uses the underlying physical relationships (e.g., material and energy balances, thermodynamic equilibrium (Fluid Package) and rate equations) to predict process performance (e.g., stream properties and operating conditions. Therefore, in process simulation, we are given the process inputs and flow sheet and are required to predict process outputs [14]. Simulation of pyrolysis process is picking up attention because of the growing interest in pyrolysis of plastic wastes for the production of fossil fuels.

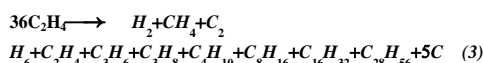
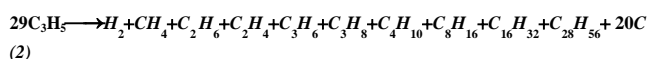
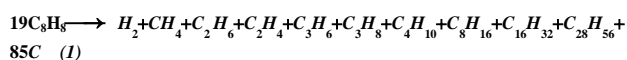
Few literatures [15, 16] having as far as I could possibly know reported a model set to give estimates of actual compositions of products obtainable from plastic solid wastes. In this present study, the simulation of different plastic wastes such as poly ethylene, polypropylene and polystyrene were carried out in Aspen Hysys V9 simulator. Aspen Hysys V9 simulator was chosen of this work because this simulator is able to perform and handled the feedstock conversion. The study will give an idea of compositions of various products expected from pyrolysis of the plastic wastes, which will help an interested to researcher in knowing the expected products and their individual compositions.

## II. SIMULATION OF PLASTIC PYROLYSIS PROCESS

The procedures are employed to accomplished the simulation of pyrolysis process with the aid of Aspen Hysys V9 are as outlined below.

### A. Component Selection

The components of both reactant and products stream, which were selected from the pure components of the component list section and added to the components in component list based on below depicted reactions.



Reaction (1), (2) & (3) represents the thermal cracking reactions of poly-styrene, poly-propylene and poly-ethylene respectively [15].

### B. Selection of Fluid Package

After the selected of components list, the fluid package that was used to estimate the physical properties of the components was also been chosen from property environment. The Fluid Package used in this work was selected to be Peng-Robinson model [16].

### C. Development of the Pyrolysis Reaction

After selecting the fluid package for the process, the reactions involved in the process were developed based on reaction (1), (2) & (3). The developed reaction set were attached to the selected Fluid Package, which was Peng-

Robinson before being used in the simulation environment of the Aspen Hysys.

### C. Simulation Environment

After every one of the steps had been preceded, then the simulation environment of the Aspen Hysys was entered. The development of the process flow diagram was accomplished by picking the parts of equipment from the palette (f<sub>4</sub> key) of the Aspen Hysys and connecting them together properly. The pyrolytic reactor which was conversion reactor where picked from the column section of the palette while the condenser was taken from the common section of the palette. After developing the flow sheet as described above, it was simulated using mass flow rate at 100 kg/hr of waste plastics such as PP, PE, PS at optimum temperature of 450 °C and a pressure of 1 atm as the feed to the Pyrolytic reactor. The vapour-liquid fraction was leaving from the top of the pyrolytic reactor, which was containing petroleum product whereas; char residue was leaved from bottom. The resulting vapour-liquid fraction was then fed into the condenser so as to obtain high purity of the desired product, which was liquid fuel. The desired product was observed to leave as liquid from the condenser, and it was stored in storage tank like silos and hopper. The results of this simulation can be viewed in workbook containing each of the equipment available in simulation environment.

## III. RESULT AND DISCUSSION

In the end of pyrolysis process, Large size waste plastic (PE, PP, PS) molecules are breakdown into smaller molecules which are Hydrogen, Methane, Ethane, Ethylene, Propene, Propane, n-butane, 1-octane, Cyclo-octane, 1-octocose and Carbon. The simulation environments of different plastic pyrolysis process (PE, PP and PS) are shown in fig 1, 2 & 3. The process which converts waste plastic into petroleum products, which was taking places in two several stages in Simulation Environment: (1) Conversion stage using Conversion reactor (Pyrolytic Reactor) and (2) condensing stage using water tube Condenser.

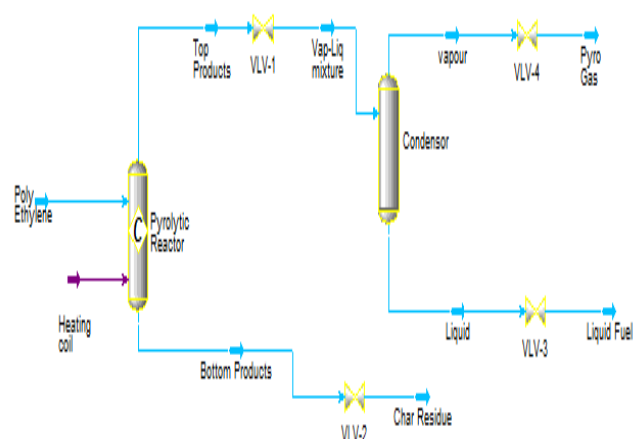


Fig 1 Poly-Ethylene thermal cracking

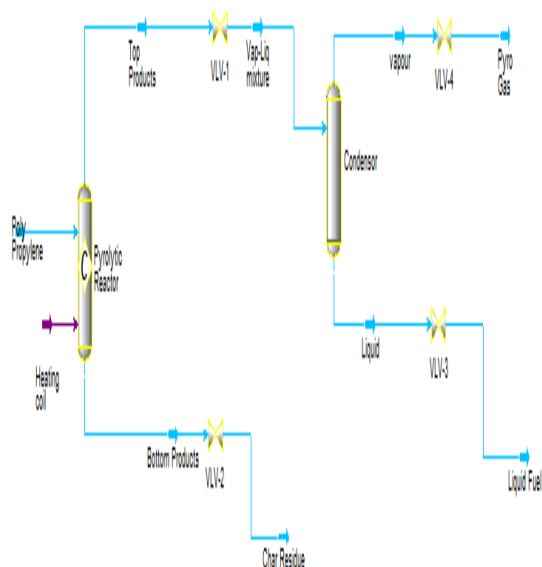


Fig 2 Poly-Propylene thermal cracking

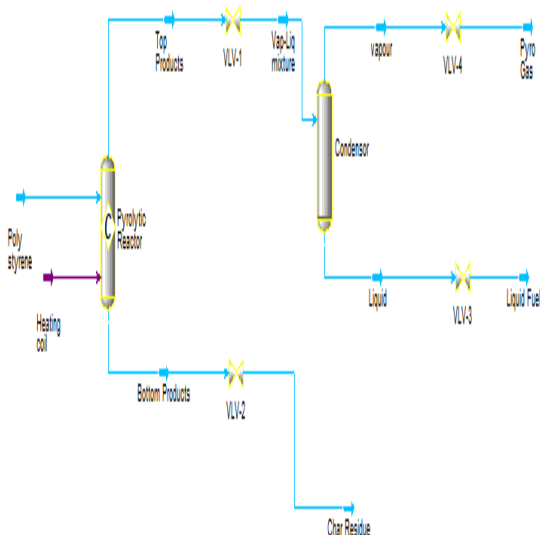


Fig 3 Poly-Styrene thermal cracking

**A. Overall Material and Energy balances around the Pyrolytic reactor**

As can be seen Table-I, II and III represents the feedstock condition of different waste plastic pyrolysis and energy flow of the pyrolytic reactor in which the conversion of Vapour-Liquid Fraction from waste plastics was takes place.

**Table-I Feedstock conditions and energy flow of the pyrolytic reactor with PE**

Name	PE Fed	Vap-liq fraction	Char residue
Vapor Fraction	0	1.0	0
Temperature [°C]	450	440	32
Pressure [atm]	1	1	1

Mass Flow [kg/hr]	100	96.63	3.37
Heat Flow [kJ/hr]	454.52	323.2	131.32

**Table-II Feedstock conditions and energy flow of the pyrolytic reactor with PP**

Name	PP Fed	Vap-liq fraction	Char residue
Vapor Fraction	0	1.0	0
Temperature [°C]	450	440	32
Pressure [atm]	1	1	1
Mass Flow [kg/hr]	100	97.44	2.56
Heat Flow [kJ/hr]	454.46	342.2	112.26

**Table-III Feedstock conditions and energy flow of the pyrolytic reactor with PS**

Name	PS Fed	Vap-liq fraction	Char residue
Vapor Fraction	0	1.0	0
Temperature [°C]	450	440	32
Pressure [atm]	1	1	1
Mass Flow [kg/hr]	100	97.67	2.33
Heat Flow [kJ/hr]	454.4	386.08	68.32

From the results in Table-I, II & III, the material stream which was plastic wastes (PE, PP&PS) fed into the pyrolytic reactor, was solid and its vapor fraction was zero. Also, char residue and vapor-liquid fraction existing at different temperature in all the cases. However, the amount of vapour-liquid fraction was more than that of the char residue. Also, it was observed from results, that the heat flow in feed is almost balances to their product, although the total heat loss around the pyrolytic reactor was found to be 0 kJ/hr. Furthermore, the reaction was endothermic reaction because its heat of reaction at 25°C was estimated to be  $-2.7 \times 10^5$  kJ/kmol.

**Table-IV** Mass flow rates of the components around the pyrolytic reactor.

Components	PE Fed (kg/hr)	Vap-liq fraction (kg/hr)	Char residue (kg/hr)
Poly Ethylene	100	0	0
Hydrogen	0	8.68	0
Methane	0	4.34	0
Ethane	0	2.27	0
Ethylene	0	0.668	0
Propene	0	0.006	0
Propane	0	0.074	0
n-butane	0	0.042	0
1-octane	0	31.8	0
Cyclo octane	0	40.2	0
1-octocosenene	0	8.55	0
Carbon	0	0	3.37

**Table-V** Mass flow rates of the components around the pyrolytic reactor.

Components	PP Fed (kg/hr)	Vap-liq fraction (kg/hr)	Char residue (kg/hr)
Polypropylene	100	0	0
Hydrogen	0	8.49	0
Methane	0	3.24	0
Ethane	0	1.52	0
Ethylene	0	0.999	0
Propene	0	0.0022	0
Propane	0	0.083	0
n-butane	0	0.0352	0
1-octane	0	32.14	0
Cyclo octane	0	42.25	0
1-octocosenene	0	8.68	0
Carbon	0	0	2.56

**Table-VI** Mass flow rate of the components around the pyrolytic reactor.

Components	PS Fed (kg/hr)	Vap-liq fraction (kg/hr)	Char residue (kg/hr)
Poly-Styrene	100	0	0
Hydrogen	0	4.769	0
Methane	0	2.31	0
Ethane	0	1.06	0
Ethylene	0	0.792	0
Propene	0	0.0025	0
Propane	0	0.079	0
n-butane	0	0.036	0

1-octane	0	32.08	0
Cyclo-octane	0	47.64	0
1-octocosenene	0	8.90	0
Carbon	0	0	2.33

Tables IV, V & VI revealed that, the mass flow rate of the individual components after thermal cracking in pyrolytic reactor. According to the results, the amount of waste plastic entering is almost same as the amount of leaving the product due to the occurrence of the reaction.

**B. Overall Material and Energy balances around the Condenser**

The feedstock condition and energy flow around the condenser during the pyrolysis process were revealed in Tables VII, VIII & IX. It expresses that, Vapor-liquid fraction entering the condenser as it is vapor fraction is 1 while leaving stream vapor fraction of pyro gas is 1 and 0 of liquid fuel. Also observed from the results, that as the temperature of the pyro gas and liquid fuel was less than that of the Vapor-liquid fraction of the condenser due to the basic principle of the condensation.

**Table-VII** Feedstock conditions and energy flow of the condenser.

Name	Vap-liq fraction	Pyro gas	Liquid fuel
Vapor Fraction	1	1	0
Temperature [°C]	440	32	36
Pressure [atm]	1	1	1
Mass Flow [kg/hr]	96.63	14.68	81.95
Heat Flow [kJ/hr]	286.08	27.86	258.19

**Table-VIII** Feedstock conditions and energy flow of the condenser.

Name	Vap-liq fraction	Pyro gas	Liquid fuel
Vapor Fraction	1	1	0
Temperature [°C]	450	32	36
Pressure [atm]	1	1	1
Mass Flow [kg/hr]	97.54	8.96	83.54
Heat Flow [kJ/hr]	342.2	27.86	258.19



**Table-IX Feedstock conditions and energy flow of the condenser.**

Name	Vap-liqu fraction	Pyro gas	Liquid fuel
Vapor Fraction	1	1	0
Temperature [°C]	440	32	36
Pressure [atm]	1	1	1
Mass Flow [kg/hr]	97.67	8.963	88.7
Heat Flow [kJ/hr]	386.08	27.89	358.19

**Table-X Mass flow rates of the components around the condenser.**

Components	Vap-liqu fraction (kg/hr)	Pyro gas (kg/hr)	Liquid fuel (kg/hr)
Poly Ethylene	0	0	0
Hydrogen	8.68	8.42	0
Methane	4.34	4.12	0
Ethane	2.27	1.354	0
Ethylene	0.668	0.666	0
Propene	0.006	0.006	0
Propane	0.074	0.072	0
n-butane	0.042	0.042	0
1-octane	31.8	0	32.3
Cyclo octane	40.2	0	40.78
1-octocosenes	8.55	0	8.87
Carbon	0	0	0

**Table-XI Mass flow rates of the components around the condenser.**

Components	Vap-liqu fraction (kg/hr)	Pyro gas (kg/h)	Liquid fuel (kg/hr)
Poly propylene	0	0	0
Hydrogen	8.49	8.224	0
Methane	3.24	3.0306	0
Ethane	1.52	1.526	0
Ethylene	0.999	0.999	0
Propene	0.0022	0.0022	0
Propane	0.083	0.083	0
n-butane	0.0352	0.0352	0
1-octane	32.14	0	32.19
Cyclo octane	42.25	0	42.93
1-octocosenes	8.68	0	8.42
Carbon	0	0	0

**Table-XII Mass flow rates of the components around the condenser.**

Components	Vap-liqu fraction (kg/hr)	Pyro gas (kg/hr)	Liquid fuel (kg/hr)
Poly Styrene	0	0	0
Hydrogen	4.769	4.74	0
Methane	2.31	2.26	0
Ethane	1.06	1.057	0
Ethylene	0.792	0.791	0
Propene	0.0025	0.0025	0
Propane	0.079	0.079	0
n-butane	0.036	0.034	0
1-octane	32.08	0	32.2
Cyclo octane	47.64	0	47.63
1-octocosenes	8.90	0	8.87
Carbon	0	0	0

Tables X, XI & XII revealed that the mass flow rates of the each component are separated from the condenser. As the condenser was only change the phase of the material and not for any mass changes. The amount of vapour-liquid fraction entering in the condenser was found to be equal to the amount of pyro gas and liquid fuel leaving it. Also it was resulting that the simulated model is a substantial one in terms liquid fuel conversion and possible condensation. Also the obtained results showed that, the conversion of liquid fuel (1-octane, Cyclo octane and 1-octocosenes) in Poly-Styrene is maximum than the other plastic wastes that produced 88.7% of liquid fuel whereas, 81.95% of Poly-Ethylene and 83.54 % of Poly-Propylene.

Among all the pyrolysis process, the conversion of Poly-Styrene was optimized than the Poly-Ethylene and Poly-Propylene polymers. The results showed that the pyrolysis in Aspen Hysys V9 was substantial one in terms of conversion.

#### IV. CONCLUSIONS

The developed simulated model for the process which converting waste plastics to useful petroleum fuel was carried out with the aid of Aspen Hysys V9 simulator showed that the model was a substantial one because the results were found to be in good association with the hypothetical standards of the feedstock in each part of equipment used. In addition, it was demonstrated from the simulations that, the material balance around each parts of the equipment were balanced due to the conservation law of mass and reaction occurrence. Furthermore, the energy balances revealed that the pyrolytic reactor having heat

duties of 0 kJ/h and its heat of reaction at 25 °C was found to be  $-2.7 \times 10^5$  kJ/kmol. The overall results obtained from this study, conclusively revealed that, the liquid fuel could be used as an alternative fossil fuels, which can reduce the negative impact to the environment.

## REFERENCES

1. Smit J, Nasr, "Urban agriculture for sustainable cities: using waste and idle land and water bodies as resources," *Environ Urban* 1992; 4(2):141-52.
2. Riber C, Petersen C and Chrisensen TH, "Chemical Composition of material fractions in Danish household waste," *Waste manag* 2009; 29(4):1251-7.
3. Donahue CJ, Exline JA and Warner C, "Chemical recycling of pop bottles: the synthesis of dibenzyl terephthalate from the plastic polyethylene terephthalate," *J chemEduc* 2003; 80(1) 79.
4. Lange J and Wyser Y, "Recent innovations in barrier technologies for plastic packaging- a review," *PackagTechnosci* 2003; 16(4):149-58
5. Pinto F, Costa P, Gulyurlu I and Cabrita "L. Pyrolysis of plastic wastes. 1) Effect of Plastic waste composition on product yield," *J Anal Appl Pyrolysis* 1999; 51(1-2): 39-55.
6. Life cycle assessment (LCA) study of plastics packaging products, Parivesh Bhawan, Central Pollution Control Board Report - March 2018.
7. Lettieri P and Al-Salem S, "Thermochemical treatment of plastic solid waste," *In: Letcher TM, Vallero D, editors. Waste: A handbook for management*; 2011, p. 233-42.
8. Scott DS, Czernik SR, Piskorz J and Radlein DSAG, "Fast pyrolysis of plastic wastes," *Energy Fuels* 1990; 4(4):407-11.
9. Xue, Y., Kelkar, A., and Bai, X. (2016), "Catalytic co-pyrolysis of biomass and polyethylene in a tandem micro pyrolyzer," *Fuel*, 166, 227-236.
10. CIPET 2009-2010. "Plastic industry statistics," [Available online on http://www.cipet.gov.in/plasticsstatics.html](http://www.cipet.gov.in/plasticsstatics.html).
11. Hossain A., Hasan R. and Islam R. 2014, "Design, Fabrication and Performance Study of a Biomass Solid Waste Pyrolysis System for Alternative Liquid Fuel Production," *Global Journal of Researches in Engineering: A Mechanical and Mechanics Engineering*, 1-11.
12. Moinuddin Sarker and Mohammad Mamunor Rashid. "Mixture of LDPE, PP and PS Plastic solid waste into Fuel by Thermolysis Process," *International Journal of Engineering and Technology Research* Vol.1, No.1, February 2013, PP: 01-16, ISN: 2327-0349 (Online).
13. Selvaganapathy T and Muthuvelayudham R, "Aromatic Liquid Hydro-carbon fuel (ALHF) production from the waste plastics using pyrolytic reactor under thermal degradation," *International Journal Management IT and Engineering* (2019) Vol. 9 Issue 4(2), April 2019, ISSN: 2249-0558 Impact Factor: 7.119
14. Mario Richard Eden., ASPEN Lab Notes, CHEN 4460, Chemical Engineering Department, Auburn University – Posted as PDF available on online.
15. Mohamed Magzoub Garieb Alla and Salma Omer Alhag Ali, "Simulation and Design for process to convert plastic waste to liquid fuel using Aspen Hysys program," *Integer. J. Engg. Res. Tech.* Vol 1(6)
16. Adeniyi A.G, Eletta O.A.A and Ighalo J.O, "Computer Aided modelling of Low Density Poly Ethylene (LDPE) Pyrolysis to produce synthetic fuels," *Nigerian Journal of Technology (NIJOTECH)* Vol. 37, No. 4, October 2018, pp. 945 – 949.

## AUTHOR'S PROFILE



**Mr. T. Selvaganapathy** received his M.E in Chemical Engineering from Annamalai University, Annamalai Nagar, Chidambaram; Tamil Nadu in the year 2009. He presently serves as an Assistant Engineer of Tamil Nadu Pollution Control Board (TNPCB). He has 11 years research experiences, 4 years teaching experiences and 7 years experiences in Tamil Nadu Pollution Control Board. He has published 4 international journals and attended 7 international conferences and 2 national conferences. He currently pursues Ph.D in Chemical Engineering at Annamalai University,

Annamalai Nagar, Chidambaram, Tamil Nadu under the guidance of Dr. R. Muthuvelayutham.



**Dr. R. Muthuvelayutham**, specialist in Environmental Bio-technology and Bio-chemical Engineering. He currently serves as a Professor at department of Chemical Engineering, Faculty of engineering and technology, Annamalai University, Annamalai Nagar, Chidambaram, and Tamilnadu. He has 21 years experiences in both research & teaching in the field of Bio-technology and Bio Engineering. He is active member of many national/international professional bodies namely IICHE and ISTE. He has been actively engaged in research since 2003. He has published more than 66 referred journals, articles and book chapters in the fields of Bio-technology and Bio Engineering.



**Dr. M. Jeyakumar** received his Ph.D in Chemical Engineering from Vinayaka Mission University, Salem, Tamil Nadu, India in 2011. He currently Working as an Assistant professor in Haramaya institute of Technology, Dire Dawa, Ethiopia and Principal (In-Charge) of Sri Ramanamaharishi college of Engineering, Thumbai, Cheyyar, Tamil Nadu, India. He has been actively engaged in research since 2008. He has published 28 international journals and 3 national journals and attended 8 international conferences and 30 national conferences. He had 15 years in both research and teaching. He went to Khulna University of engineering and technology (KUET) Bangladesh as a Chair Person of Conference on "2<sup>nd</sup> international conferences on solid waste management in in developing countries" held on 13-15 February 2011. He is a member of many national/international professional bodies namely IICHE, ISTE, BIGFIN and BRSI.