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Grey Water Treatment Systems under Controlled Laboratory Conditions

Sachin Madhavrao Kanawade

Abstract
A comparison of chemical versus biological package grey water treatment systems was undertaken using a new laboratory based protocol that included a synthetic grey water formulation that mimics average bathroom and laundry grey water in Australia. The results for chemical, nutrient and metals removal showed that the treatment systems behaved very differently under the test conditions. The chemical system was able to remove most of the components of grey water that could be detrimental to the environment and produced high quality product water. The biological system was only able to remove some of the components of the grey water, and did not produce the same quality of product water. However, the product water quality was found to improve continually over the duration of testing. It was concluded that for the current composition of Indian grey water the chemical based technology produced the highest quality product but that other environmental costs, such as chemical use and energy also need to be assessed. If grey water compositions change with the use of more biodegradable, low environmental impact personal care and cleaning products, biological treatment systems may be better suited to treating grey water in the future.

Keywords: chemical, nutrient, recycling, reuse, testing protocol, wastewater

1. Introduction
There is currently an increasing focus around the globe on water saving measures, better management of water supplies, and policies to reduce wastewater discharges to receiving waters. In India, numerous strategies including the use of grey water treatment systems are being supported by government agencies (Our Water Our Future Action Plan, 2004; Melbourne Water Resources Strategy, 2002) [16]. This has led to an increased interest in developing new grey water recycling technologies, with many of these also trying to meet the criteria of minimum environmental impact. A number of grey water treatment systems are already available for purchase and many more are awaiting approval from the relevant organisations in various states before being available for sale. Currently, there is no one standard protocol to which grey water systems are tested and regulated; rather states and territories each have their own legislation for grey water collection, treatment and use. These range from very stringent regulations requiring virus and bacterial testing in field situations, to limited regulation for the direct use of untreated grey water at a household level. These factors have led to calls for the development of a standard testing protocol to allow small scale grey water technologies to be tested to a uniform set of conditions relevant to India.
Current regulatory requirements in Australia imply treated grey water should be free of pathogenic micro-organisms, particularly if it is to be stored prior to re-use (EPA, 2003) [9]. Although not an issue for human health, grey water also contains components that can be detrimental to plants and the environment in both the short and long term. In the short term there are the potential impacts of high pH and salinity and whilst in the longer term there is the potential for accumulation of certain components in the soil causing long term environmental problems. Testing protocols and synthetic grey water formulations for assessing the performance of grey water treatment technologies have been developed internationally over the past decade (Brown and Palmer, 2002) [2]; grey water composition has, however, been found to vary significantly between countries and regions. This is due to the variability in household products used, differences in water quality and water usage, and variability in the composition of grey water due to the inclusion or exclusion of various

Waste streams. For example, in Australia waste water from the laundry is almost always included in grey water, whereas in Europe research generally excludes the laundry component (Jefferson, 2004) [14]. In the current work, a laboratory-based protocol (Diaper *et al*., 2005) [5] and synthetic grey water formulation were developed in-house and used to test grey water treatment systems for chemical and microbiological performance. These methods were developed in collaboration with a local advisory group including water company representatives and local health and environmental regulatory bodies. In addition, state guidelines relating to the treatment and reuse of grey water as well as available literature and data relating to the quality and composition of grey water were assessed and reviewed (Jeppesen, 1996 [15], Eriksson *et al*., 2002) [11]. This paper presents results obtained using the synthetic greywater formulation and laboratory based testing protocol for two package grey water treatment systems available in India. The assessment focussed on the performance of the two systems in removing organic material, some specific cations, nitrogen and phosphorus. For the purposes of this research, technologies using treatment methods such as chemical dosing, biological aeration, membrane or media filtration, and flocculation were considered. Irrigation systems and technologies such as sand mounds and diversion systems were excluded. One technology was based on chemical treatment, flocculation, filtration and UV disinfection (Technology A), while the other was primarily biological, with initial settling storage, fixed film biological filtration and chemical disinfection (Technology B). These technologies were chosen as they are a good representation of what is available on the Indian market; both are manufactured and have received approval for sale from the relevant authorities in at least several States of India.

2. Material & Methods

The two technologies tested had different operating regimes and cycle times as outlined in Table 1. The treatment cycle for Technology A was approximately 40 min with 225 L of grey water feed being processed during each cycle, whereas the treatment cycle for Technology B was significantly longer at 7-8 hours to process 100 L of grey water feed. Technology B was provided with biological treatment cells that were pre-conditioned in the field and transported to the laboratory so that there would be reasonable biofilm growth on the media to start experimental work. Figure 1 shows the layout of the system that was used to test both technologies. Both treatment systems were installed by representatives of the technology manufacturers.

Table 1: Operational parameters for greywater treatment technologies tested

Operational Parameters	Technology A	Technology B
Treatment process stages	Flocculent dosing, four stage filtration and UV disinfection	Settling, filtration and bromine /chlorine disinfection
Mode of operation	Sequencing batch reactor	Continuous processing
Commissioning period required	None	3-6 months
Capacity	1600 L/day	300 L/day
Total batch treatment cycle	39.5 min (225 L)	8 hours (100 L)
Storage volume	Variable, dependent on customer requirements	Variable, dependent on customer requirements
Settling Time (prior to treatment cycle)	N/A	1 – 6 hours
Flocculent dosing time	20 min	N/A
Back flush	90 sec	N/A
Feed Cycle	N/A	Feed on -5 min/feed off -17 min

Installation included all connections from the laboratory synthetic grey water feed tank and to the final product storage tanks, along with any alterations to the technologies required during operation. As the technologies differed significantly in treatment times and processes, hydraulic residence time of the grey water was determined using a sodium chloride tracer and this was used as the basis for determining the testing schedule for each unit.

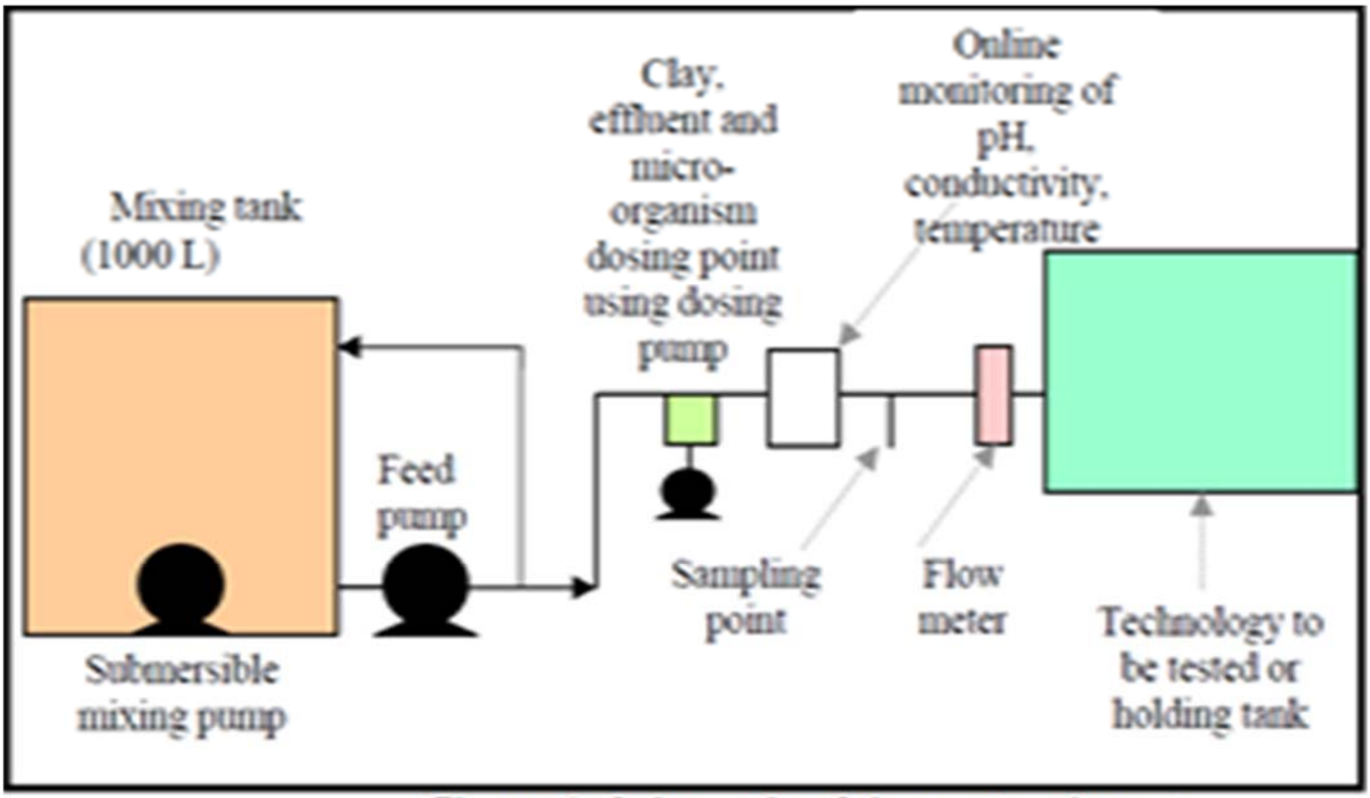

Figure 1: Schematic of the system layout

Testing for chemical and physical parameters was carried out using 10 batches of grey water feed for each system. The volume fed and processed per batch was based on the capacity of the technology (i.e. 225 L of feed per batch for Technology A and 100 L per batch for Technology B). Samples of both the feed and product water were collected for analysis to assess treatment performance. Samples were analysed by a NATA (National Association of Testing Authorities) accredited laboratory using standard methods (APHA, 2005) [1]. This included analysis for suspended solids, chemical oxygen demand (COD), biological oxygen demand (BOD), conductivity, pH, turbidity, total phosphorous, total Kjeldahl nitrogen (TKN), boron, and pathogen indicators, E. coli and Faecal Enterococci. These parameters were selected after an extensive literature review and investigation of grey water components likely to have detrimental impacts on soils, plant life and other water bodies. Testing was also carried out on grey water feed and product water samples from both technologies for calcium, magnesium, sodium, zinc and aluminium and boron. Calcium, magnesium and sodium analysis was required to obtain a value for sodium adsorption ratio (SAR), which is an indicator used to assess the impact of treated water on soil infiltration. Zinc levels approaching or above the guideline values for irrigation have been found in grey water (Christova-Boal, 1996 [3]; Hypes, 1974) [13], and aluminium is often present in personal care products, hence the inclusion of these metals for testing. Boron analysis was included as it is present in many laundry detergents and is known to have acute toxicity to plants. Concentrations found in grey water (Friedler, 2004) [12] are often above the recommended maximum value for irrigation waters (EPA, 1991) [8], however the analysis technique used was not sensitive enough to allow detection below 1.5 mg/L. The pH, temperature, conductivity and turbidity of the grey water feed were monitored during testing using on-line probes. During testing of each technology, random samples of product water were analysed in house for pH, conductivity and turbidity as these parameters were found to be good indicators of any problems with a particular treatment system. In future these parameters could be used for process control if the interrelationships with other water quality parameters can be determined.

3. Results and Discussion

The treatment systems performed very differently under the test conditions, and the results for Technologies A and B are shown in Table 2 and 3, respectively. It should be noted that the slight variations in some of the grey water feed values between the two technologies were due to minor adjustments being made to the synthetic grey water formulation between testing the two technologies to bring the chemical and physical parameters into the correct range for average grey water. Results were compared to Class A recycled water quality requirements (EPA, 2003) [9], India recommended standard for water to be used for unrestricted irrigation end uses and indoor purposes such as toilet flushing. The results for chemical analysis show that Technology A was able to remove more than 95% of BOD, SS and COD. Technology B was able to remove 95% of BOD and SS, however significantly less COD at 56%. The comparison of removal of TOC shows a similar trend where Technology A was able to remove 93% but Technology B was only able to remove 33%. Given that Technology B is a biological-based system the results for COD and TOC were not unexpected as it has no mechanisms for removing non-biodegradable organic components. Although the conductivity of the product water had increased slightly after treatment by both technologies (from an average of 281 to 299 µS/cm for Technology A and from 324 to 339 µS/cm for Technology B), an analysis of variance (ANOVA) showed that neither increase was statistically significant ($p<0.001$). The pH of the final product water decreased slightly for Technology B from an average of 7.1 in the grey water feed to an average of 6.7 in the final product water, whilst an increase in pH was observed for Technology A, from an average of 8.3 in the grey water feed to 9.4 in the final product water. The increases in pH and conductivity for Technology A were likely due to the materials used in the flocculation process by this technology, details of which were not available to the authors. The technology manufacturer reformulated the flocculation agent as a consequence of these results but the new flocculation agent was not tested in this study. Technology A was able to remove 99% of turbidity from the grey water feed and Technology B removed less at 77%.

Table 2: Chemical and metals testing results for Technology A

Parameter (mg/L unless otherwise stated)	Average feed (± St Dev)	Average product (± St Dev)	% Removal	Class A requirement
BOD	125 (± 10)	5.5 (± 1.3)	96	< 10 mg/L BOD
Suspended Solids (SS)	70 (± 14)	1.8 (± 0.6)	97	< 5 mg/L SS
COD	224 (± 15)	8.3 (± 3.9)	96	^
TKN	5.4 (± 0.4)	1.6 (± 0.3)	71	^
Total P	9.1 (± 0.2)	1.9 (± 1.7)	79	^
TOC	48 (± 12)	3.5 (± 1.5)	93	^
Conductivity (µS/cm)	281 (±7)	299 (± 12)	*	^
pH	8.3 (± 0.7)	9.4 (± 0.2)	#	6 – 9
Turbidity (NTU)	27 (± 5)	0.4 (± 0.3)	99	< 2 NTU
Total coliforms (cfu/100mL)	>2400	3.2	~$\log_{10}3$	^
E.coli (cfu/100mL)	83	0	~$\log_{10}2$	< 10 *E.coli* cfu/100 mL
F.Enterococci (cfu/100mL)	7.8	0	~$\log_{10}1$	^
Calcium (mg/L)	7.4 (± 0.4)	8.5 (± 0.9)	*	^
Magnesium (mg/L)	1.5 (± 0.04)	2.5 (± 0.4)	*	^
Sodium (mg/L)	56 (± 1)	51 (± 3)	8	^
Zinc (mg/L)	<0.01	<0.001	-	^
Aluminum (mg/L)	1.15 (± 0.5)	<0.3	95	^

* = Increase in product, # = N/A, ^ =No requirement

Technology a removed 71% of TKN, compared to 0% removal by Technology B. Removal of total phosphorus from the grey water feed showed similar trends, where Technology A removed 79% and Technology B gave 0% removal. As Technology B was an aerobic biological treatment process operating on a similar principle to a trickling filter high levels of nitrogen and phosphorus removal were not expected. More detailed investigation of the nitrogen species would be required to establish whether nitricification was occurring. The total treatment train for both technologies removed the bacteria and other microorganisms from the grey water feed. These were levels of total coliforms, E. coli and F. Enterococci that might be expected to be present in an average grey water. However additional testing before and after chemical disinfection on Technology B indicated that the disinfection stage was responsible for all microorganism removal. Final product water samples from Technology A met almost all the criteria for Class A effluent and the NSW Health Water Quality Guidelines (2005) for single dwellings with the exception of pH. Product water samples from Technology B, although providing good removals for several parameters, did not meet the Class A effluent standard as the turbidity in the final product water samples remained well over the 2 NTU limit throughout the testing. Treatment cells for Technology B were preconditioned in the field and then fed with the synthetic grey water formulation for 3 weeks in the laboratory to allow the biofilm to adjust to a potentially slightly different grey water composition prior to commencing testing. After the 3 week commissioning period, the turbidity in the product water had decreased to a stable point. The levels of bacteria being removed from the grey water feed had also improved significantly, with no Coliforms, E. coli or F. Enterococci present in the product water. Chemical testing was commenced as the technology appeared to have stabilised. However, the quality of the product water was found to improve during testing suggesting that the biofilm initially present may still have been developing, or had been disturbed during transport and had over time re-stabilised or simply required more time to adjust to the different environment (i.e. warmer, constant laboratory temperature) and grey water composition.

Table 3: Chemical and metals testing results for Technology B

Parameter (mg/L unless otherwise stated)	Average feed (± St Dev)	Average product (± St Dev)	% Removal
BOD	105 (± 12)	10.5 (± 3.5)	>95
Suspended Solids	66 (± 44)	4.2 (± 2.3)	95
COD	247 (± 32)	116 (± 35)	56
TKN	5.2 (± 0.2)	6.1 (± 1.8)	0
Total P	16.8 (± 1.4)	16.5 (± 1.1)	0
TOC	45 (± 9.1)	31.8 (± 8.5)	33
Conductivity (µS/cm)	321 (± 14)	340 (± 8)	0
pH	7.13 (± 0.09)	6.65 (± 0.08)	N/A
Turbidity (NTU)	47 (± 24)	11.4 (± 5)	77
Total coliforms (cfu/100mL)	>2400	0	~$\log_{10}3$
E.coli (cfu/100mL)	67	0	~$\log_{10}2$
F.Enterococci (cfu/100mL)	>100	0	~$\log_{10}2$
Calcium (mg/L)	7.4 (± 0.3)	6.8 (± 0.4)	0
Magnesium (mg/L)	1.44 (± 0.09)	1.49 (± 0.08)	0
Sodium (mg/L)	64 (± 1)	66 (± 1)	0
Zinc (mg/L)	<0.02	0.08 (± 0.03)	0
Aluminium (mg/L)	1.5 (± 0.9)	0.6 (± 0.3)	57

The results for metals analysis (Table 2) show Technology A was able to remove greater than 90% of zinc and aluminium from the synthetic grey water feed. However, initial zinc concentrations in the feed were close to the limit of detection of the analysis method. Aluminium concentrations were substantially reduced although there was a high variability in the feed concentration. Minimal removal of sodium and a significant increase in magnesium concentration was observed. The increase in magnesium concentration may be due to the components used in the flocculent; however the composition was not disclosed by the technology manufacturer. Technology B showed a 57% decrease in aluminium concentration in the final product water (Table 3). This may be due to some physical processes as deodorant contains aluminium chlorohydrate, a compound which may behave similarly to some flocculent products used in wastewater treatment. It is possible that this compound may have caused the formation of flocs which could have settled in the pre-treatment storage. A small but significant increase was observed for zinc concentrations in the product water after treatment by Technology B. An explanation for this could be that Zn was leaching from system fittings. As the technologies tested were new this effect may be more obvious due to new valves and system components (Comber and Gunn, 1996) [4]. There are numerous advantages and disadvantages for both chemical and biological process based grey water treatment technologies. A big advantage of chemical based technologies is that very little start up time is required, although this is offset by the fact that it involves the use of chemicals which may contribute to environmental impacts and issues as well as cost. The chemical based technology (Technology A) used in this testing was a discrete unit which required minimal householder maintenance but produced a high quality effluent; the energy use associated with these units however, may be significantly higher than that of a biological system due to the use of pumps and switching valves and pressure filtration. The use of consumable materials in these systems such as flocculants may also add additional costs. A major disadvantage of the biologically-based treatment technology (Technology B) was the considerably long start up time required for biofilm growth on the selected media and acclimation to feed composition. In severe cases, for example where bleach or other harsh chemical cleaners may be accidentally disposed of and mixed in with the grey water, this may require the whole biofilm growth process to be re-established. Another significant problem is that for an untrained operator such as a householder there could be very little warning that the biological system is not performing well thus allowing potentially untreated product water to be used.

4. Conclusions

The synthetic grey water formulation that was developed as part of this research was proven to meet the parameter range criteria and mimic an average grey water in composition as well as providing a suitable medium for the transport of micro-organisms for testing. The testing protocol was found to work successfully to allow each technology to be evaluated rigorously. Technology A was found to remove most of the components in grey water that might be detrimental to the environment and produced high quality product water that would be suitable for many applications around the home such as toilet flushing, surface and sub-surface garden irrigation, and car washing. Technology B was not able to remove as many of the components that may be detrimental to the environment and most metals were not removed at all. The technology did not remove the nutrients phosphorus and nitrogen but more research is required to understand whether the impacts of these are beneficial or detrimental in the form and load applied in the treated grey water. Although not discussed in this paper the ability of each technology to remove micro-organisms and pathogens would be a very important factor in determining the end use applications of the product water if treatment are applied at a scale larger than a single house. Further work that would be valuable to compliment the current research would be to assess the performance of technologies with a synthetic grey water formulation using more biodegradable, low environmental impact personal care and cleaning products and then use this to assess and compare the performance of the biological and chemical based technologies.

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6. References

1. APHA. Standard Methods for the Examination of Water and Wastewater. Baltimore, USA: Port City Press, 2005.
2. Brown R, Palmer A. Water Reclamation Standard; Laboratory testing of systemsusing greywater. Technical Note TN 7/2002 BSRIA Ltd., Bracknell, UK, 2002.
3. Christova-BoalD,Eden R, McFarlane S. An investigation intogreywaterreuseforresidential properties. Desalination 1996; 106:391-397.
4. Comber S. Gunn A. Heavy metals entering sewage-treatment works from domestic sources. Journal of the Chartered Institution of Water and Environmental Management. 1996; 10(2):137-142.
5. Diaper C, O'Halloran R, Critchley M, Anderson N. proposed greywater system testing protocol, On-site '05: Performance Assessment for On-site Systems-Regulation, Operation and Monitoring. Armidale, New South Wales, 2005, 27-30.
6. DPIWE. Environmental Guidelines for the use of recycled water in Tasmania, 2002.
7. DepartmentofPrimaryIndustries.Water and Environment, Tasmania, Australia.
8. EPA. Victoria Guidelines for irrigation. Environment Protection Authority, Victoria, Australia, 1991.
9. EPA. Guidelines for environmental management: Use of reclaimed water. Environment Protection Authority, Victoria, Australia, 2003.
10. EPA. Victoria Draft Guidelines for Environmental Management:DualPipe water Recycling Schemes-Health and Environmental Risk Management. Environment Protection Authority, Victoria, Australia, 2005.
11. Eriksson E, Auffarth K, Henze M, Ledin A. Characteristics of grey wastewater. Urban Water 2002; 4:85-104.
12. Friedler E. Quality of individual domestic greywater streams and its implication for on-site treatment and reuse possibilities. Environmental Technology 2004; 25:997-1008.
13. Hypes W. Characterisation of typical household greywater. In J H T. Winneberger (Ed) Manual of greywater treatment practice. Michigan: Ann Arbor Science, 1974, 79-88.
14. Jefferson B, Palmer A, Jeffrey P, Stuetz R, Judd S. Greywater characterisation and its impact on the selection and operation of technologies for urban reuse. Water Science and Technology 2004; 50(2):157-164
15. Jeppesen B. Model guidelines for domestic greywater reuse for Australia. Urban Water Research Association of Australia (UWRAA) Research Report No. 107, Brisbane City Council. 1996.
16. Melbourne Water Resources Strategy. Final Report: Stage 3 in developing a Water Resources Strategy for the Greater Melbourne area. Water Resources Strategy Committee. Melbourne Water, Victoria, Australia, 2002.
17. NSW Health. Interim Guidance for grey water and sewage recycling in multi-unit dwellings and commercial premises. New South Wales Health, Australia, 2005.
18. Our Water Our Future. Securing our water future together, Victorian Government Department of Sustainability and the Environment. Australia, 2004.
19. South East Water. Draft Testing Protocol for Proposed Technologies Treating Grey Water, Victoria, Australia. November, 2003.

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Dr. Sachin Madhavrao Kanawade was born in 11 March 1978 at Nashik, Maharashtra, India. His native place is Nimgaonpaga, Tal-Sangamneer, Dist-A'Nagar, Maharashtra, India. He received his Bachelor's Degree in Chemical Engineering from Pravara Rural Education Society's Pravara Rural Engineering College, Pravaranagar (Loni) which is affiliated to Pune University in India in Nov.2001.Then he worked as a Production Officer in different Multinational Chemical Industries in India (2001 to 2008) like M/S Watson Pharma Ltd, Ambernath, MIDC, Mumbai, MS, M/S Glenmark Pharmaceuticals Ltd, Mohol, Dist. Solapur, MS, M/S Sun Pharmaceutical Industries Ltd, A. Nagar, MIDC, MS for 7 years. Then he changes his field. He joined K. K. Wagh College, Nasik, MS, India in 2008 & worked as Lecturer for 2 years. At the same time he received his Master of Engineering in Environmental Engineering from Pravara Rural Education Society's Pravara Rural Engineering College, Loni in Dec. 2010. Then he joined Pravara Rural Education Society's Sir Visvesvaraya Institute of Technology, Chincholi, Tal-Sinnar, Dist-Nasik, M.S. India in 2010 & worked as Assistant Professor in Chemical Engineering Department for 5 years. In the same period he completed his PhD Degree in Chemical Engineering in session 2011-2014 from Kumar Bhaskar Varma Sanskrit and Ancient Studies University Nalbari, Assam, India. Presently he is Associate Professor at Dr. Vasantraodada Patil Shetkari Shikshan Mandal's Padmabhooshan Vasantraodada Patil Institute of Technology, Budhgaon, Tal-Miraj, Dist-Sangali, Maharashtra, India in Chemical Engineering Department.
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