Chapter 5.

Discussion

The Experiments were conducted in two phases, in the first phase suitability of the sludges for *Eisenia fetida* was tested with respect to growth and population buildup of worms. Observations were recorded at fortnightly intervals for selecting two mixtures of each sludge with cattle dung for the second phase of the experiment. The mixtures were selected on the basis of highest growth rate and population buildup of worms and then inoculated with a variable weight of worms (g)/kg feed mixture for optimizing the time taken for degradation of these mixtures.

5.1 Growth and Fecundity of *Eisenia fetida*

Biosludges from the three industries selected for the present study were not accepted as feed and worms showed either escaping behaviour or there was mortality of worms even after stabilization of the sludge for 21 days, thus these were mixed with the cattle dung in various proportions. Cattle dung not only increased acceptance of a sludge as feed but it also enhanced population buildup of worms. Liu and Price (2011) also reported that earthworm had very low survival rate in fresh coffee ground but addition of nutrient rich organic waste increased the worm survival rates and earthworm biomass production. Flegel and Schreder (2000) reported that changes in chemical composition of feed, and production of toxic or foul smelling gases (ammonia, carbon dioxide, nitrogen oxide etc.) or high C: N ratio of the initial substrate might have been some of the factors responsible for earthworm mortality. It was observed that 50:50, 30:70 and 25:75 ratios respectively of beverage, paper and distillery industry sludge with cattle dung gave best growth and population buildup of *Ei. fetida*. Results were further strengthened by the response surface design which indicated that for best population buildup of worms and for fast degradation the beverage, paper mill and distillery industry sludge should be mixed with cattle dung in the ratio of 48: 52, 30:70 and 21:79 respectively (very near to the observed values). The ideal harvest time was 110 days for beverage biosludge, 100 days for paper mill sludge and 150 days for distillery sludge as after these durations worm biomass and cocoon production started to decline and moreover, compost started granulating on the surface, which
indicated exhaustion of nutrients in the mixture. Earlier Elvira et al. (1998) and Banu et al. (2001) also observed that 30:70 mixture of paper mill sludge with cow dung and sewage sludge was most favourable for vermicomposting by La. mauritii and Eu. eugeniae and Ei. anderi. For distillery sludge Suthar (2008) noticed that rate of biomass gain, growth (mg weight/ worm/ per week) and cocoon production was maximum in the mixture with 40% sludge and minimum in the mixture with 80% sludge.

In the present study clitellum appeared between 15th to 30th day in all the feed mixtures except BV5 of beverage sludge between 30th to 45th day in all the feed mixtures of paper mill sludge except PV5 and between 45th to 60th day in all the feed mixtures of distillery sludge except DV5 and DV6. Maximum number of cocoons was observed in BV2, PV1 and DV2 mixtures of beverage, paper and distillery sludge respectively. The observation is supported by the response surface curve which indicated that beverage, distillery and paper mill sludge must be mixed with cattle dung in the ratio of 44.2: 55.8, 25: 75 and 24.5: 75.5 respectively for maximum cocoon production. Increasing concentration of industrial sludges in the mixtures of the present study brought a decline in the rate of degradation and drastically affected the worms as there was a delay as well as a decline in cocoon production. Corresponding to the number of cocoons there was a variation in the number of hatchlings in various sludges of the present study. Maximum number of hatchlings was recorded in BV3, PV2 and DV3 for beverage, paper and distillery sludge respectively. The response surface curve indicated 47.4% and 17.1% to be the best proportion of the beverage and distillery sludge with cattle dung for production of highest number of hatchlings by Ei. fetida. Number of hatchlings was also negatively correlated with the proportion of all the three sludges in the feed mixtures and it was minimum in all the mixtures of sludge. Quality of a feed actually determines growth of worms and onset as well as rate of cocoon production and the rate is higher in the substrates having a low C: N ratio (Bostrom, 1987; Shiptalo et al., 1988; Suthar, 2008; Kumar et al., 2010). According to response surface curve 50.1% beverage biosludge and 81.8% distillery sludge in the cattle dung would give maximum worm biomass. Worm biomass, however, increased with the increasing proportion of paper mill sludge and distillery sludge in the feed mixture but it corresponded with a low rate of cocoon production in these sludges. It seems that the energy otherwise to be used for reproduction was diverted towards weight gain by the worms. This gets corroborated by the findings of Elvira et
that in paper sludge, earthworms had more mean biomass and low reproductive rate. Several other workers have also observed a higher rate of cocoon production by small to medium sized epigeic earthworms (Kale et al., 1982; Senapati and Sahu, 1993; Chaudhuri and Bhattacharjee, 2002; Barne and Striganova, 2005; Suthar, 2008). Higher C:N ratio of the mixtures with higher content of sludge might have delayed clitellum development and cocoon production by Ei. fetida in the present study as low level of nitrogen in the feed mixture is considered a limiting factor for the growth of worms (Butt, 1993). However, Lavelle (1981) found a positive relationship between the size of an adult worm and number of cocoons produced by it.

In the second phase of the present study worm biomass was observed to decline along with a delay as well as a decline in cocoon production with an increasing number of worms and increasing proportion of a sludge in the feed mixtures. Similar observation was made for Ei. fetida by Neuhauser et al. (1980), Reinecke and Viljoen (1991) and Garg et al. (2008), for Ei. anderi by Dominguez and Edward (1997) and for Pe. excavatus by Edwards et al. (1998) that growth rate of worms and rate of degradation was higher at higher stocking densities, however, biomass gain per worm was more as well as sexual maturity was attained earlier at lower stocking densities. Datar et al. (1997) and Ndegwa et al. (2000) observed decrease in biomass with increase in stocking density. Raphael and Velmourougane (2011) observed degradation of coffee pulp without earthworm after 205 days in comparison to 112 days with exotic worms. In our study also with highest stocking density (25g/kg feed) beverage, paper and distillery industry sludges were converted into vermicompost within 95, 77 and 98 days in comparison to 105, 85 and 110 days with 12.5 g worms/kg feed mixture, 110, 98 and 120 days with 7.5 g worms/kg feed and 190 (beverage), 210 (pulp and paper mill) and 250 days (distillery sludge) with 0g worms/kg mixture (traditional aerobic composting) while sexual maturity showed a negative correlation (r = 0.98, 0.99 and 0.94 respectively) with the proportion of sludge in the mixture. Collective use of carbon as a source of energy and nitrogen for building cell structure by earthworms and microbes could be responsible for a faster decomposition of organic matter (Venkatesh and Eevera, 2008).
5.2 Physico-chemical parameters:

When the mixtures of each sludge with cattle dung were subjected to vermicomposting and traditional aerobic composting, faster remediation (with respect to improvement of physico-chemical characteristics) was observed with vermicomposting.

5.2.1 Colour and Texture

Initial colour of the beverage, paper and distillery sludge was light brown, light grey and dark brown respectively. The products of vermicomposting from the three sludges had a dark brown colour and soft granular texture. Change in colour is due to conversion of organic matter to humus by the enzymatic action of worms and microbes (Arancon et al., 2004b). The end products of vermicomposting from all the mixtures of the present sludge had the same colour but there was a slight variation the colour of the products of traditional aerobic composting.

5.2.2 pH and EC

There was a significant increase in pH of the products over initial (p< 0.05) but the correlation of pH with the concentration of biosludge was negative for the products of both vermicomposting and traditional aerobic composting of beverage and paper industry biosludge. On the other hand increase in pH was positively correlated with the concentration of distillery sludge in the feed mixtures subjected to both vermicomposting and traditional aerobic composting. Among all the mixtures increase in pH (18.9%) was maximum in BV$_5$ and minimum in BV$_1$ (4.5%) with vermicomposting. With traditional aerobic composting a rise in pH was noticed in all the products of beverage and distillery sludge but there was a decrease in pH of the mixtures of paper mill sludge. Increase in pH was maximum (8.7%) in BT$_5$ of beverage sludge and minimum (0.8%) in DT$_5$ of distillery sludge. Earthworms develop a mutual relationship with the microbes and selectively increase population of catabolically more active microbes (Aira et al., 2007), therefore faster degradation of short chain fatty acids and precipitation of calcium carbonate may have brought a higher rise in pH of the products of vermicomposting (Tognetti et al., 2007a) after the stipulated time of the present study in comparison to the products of traditional aerobic composting. It is also known that the excess of
organic nitrogen not required by microbes is released as ammonia which gets dissolved in water and increases pH of the mixtures (Rynk et al., 1992; Beck-friis et al., 2001; Mainoo et al., 2009). Humus also binds with free cations and leads to an increase in pH of the soil (Brady and Weil, 2002) this may be the reason for a smaller rise in pH of the products of traditional aerobic composting in comparison to the products of vermicomposting. Jadia and Fulekar (2008) however, noticed an increase in the pH during composting and vermicomposting of vegetable waste. pH of the products in the second phase of present study showed a negative correlation with the stocking density of *Ei. fetida* (g)/kg feed mixture and out of the three sludges maximum decrease in pH (15.1%) over initial was noticed in BE3 of beverage biosludge. Datar et al. (1997) also reported a decline in pH of the products with time and earthworm loading. Higher decline in pH may be due to higher production of intermediates like fulvic acid and humic acid during decomposition of organic matter (Albanell et al., 1988, Pramanik et al., 2007) or due to production of more CO2 at higher stocking densities (Hartenstein and Hartenstein, 1981; Haimi and Hutha, 1986; Mitchell, 1997; Elvira et al., 1998; Atiyeh et al., 2000; Chaudhuri et al., 2000; Alves et al., 2001; Gunadi and Edwards, 2003; Loh et al., 2005; Raphael and Velmourougane, 2011). Ndewga et al. (2000) suggested that the larger the increase in biomass, the greater the reduction of volatile solids and a shift towards acidic condition. Li et al. (2011) also reported a decrease in pH during vermicomposting of sewage sludge and attributed the decline to bioconversion of organic acids or higher mineralization of nitrogen and phosphorous into nitrites/nitrates and orthophosphate, respectively.

EC was found to decline significantly over initial in the products of both vermicomposting and traditional aerobic composting (p< 0.01) and it showed a negative correlation with the concentration of beverage and paper mill sludge but a positive correlation with distillery sludge in the mixtures. Out of the three industrial sludges maximum decrease in EC was noticed in PV2 (41.5%) of paper mill sludge followed by BV1 (28.5%) of beverage sludge and DV1 (11.1%) of distillery sludge. The decline in EC of the products of vermicomposting and traditional aerobic composting may be due to stabilization of the mixtures and reduction of ions (Wang and wong, 2004; Garg et al., 2006; Singh et al., 2010). However, in the second phase, with increasing stocking density of *Ei. fetida* increase in EC was 65.5% over initial (maximum) in B’E1 of beverage biosludge and it was 18.6% (minimum) in DE3 of
distillery sludge. In a closed system there is a rise in mineral salts with a corresponding loss of weight of organic matter during composting and vermicomposting and therefore there is an increase in electrical conductivity (Khwairakpam and Bhargava, 2009b; Yadav and Garg, 2009). Karmegam and Daniel (2009) correlated the increase in EC to increased levels of soluble salts in available form due to mineralization of the feed mixture by earthworm and micro-organisms. Correspondingly increase in sodium and potassium content in the mixtures may also be responsible for the rise in EC of the products of vermicomposting (Guoxue et al., 2001).

5.2.3 Nitrogen:

Nitrogen content increased over initial in the products of vermicomposting while it decreased in the products of traditional aerobic composting of the three industrial sludges. Nitrogen content showed a positive correlation with the concentration of biosludge in the feed mixtures for beverage sludge but a negative correlation was noticed with the proportion of pulp and paper and distillery sludge in the feed mixture. Maximum increase in nitrogen (68.9%) was noticed in PV1 (cattle dung), however, out of the mixtures of the three sludges and cattle dung highest increase in nitrogen over initial was 67.3% for PV2, 31.3% for DV2 and 9.86% for BV2. Variation in the increase in nitrogen content of the products could be due to the variation in the contents of nutrients in these sludges because initial physico-chemical characteristics of a waste determine the physico-chemical parameters of the product (Suthar, 2008). Nitrogen is fixed by microbes as well as it is also added in the form of mucus, nitrogenous excretory substances, hormones and enzymes by the worms during vermicomposting (Garg and Kaushik, 2005; Hobson et al., 2005; Suthar, 2006; Suthar, 2010, Zularisam et al., 2010; Garg and Gupta, 2011) which may be the reason for higher nitrogen content of the products of vermicomposting in the present study. Kavian and Ghatnekar (1991) suggested that enhanced population of Azotobacter and Rhizobium in the vermicast during vermicomposting of paper mill sludge was responsible for an increase in the nitrogen content of the products. Needham (1957) reported that approximately one half of daily nitrogen loss by earthworm is through mucus secretion from the gland cells in the epidermis. Mucus consisting of mucoproteins is actually secreted to prevent dessication and facilitate respiration. The increase in nitrogen may also be due to decay of the dead worms as considerable portion of dry weight of a worm is protein (Tripathi and Bhardwaj, 2004). Plaza et al. (2005, 2008) have reported that nitrogen increased significantly due to
mineralization of carbon rich materials by the bacteria. The decline in nitrogen in the products of traditional aerobic composting could have been due to use of nitrogen by the rapidly multiplying heterotrophic bacteria (Brady and Weil, 2002) or due to an increased production of ammonia by these microbes (Guest et al., 2001). In the second phase of the experiment maximum increase over initial in nitrogen was noticed in P’E2 (134.3%), DE2 (42.6%) and BE2 (25%) of paper, distillery and beverage sludge. Higher increase in nitrogen with higher worm density clearly indicated that mutual action of worms and microbes enhanced nitrogen content of the products. At the same time decline in nitrogen in the products of BE0, DE0 and PE0 also confirmed previous observations that earthworms enhance metabolically active microbes and help in higher nitrogen fixation in the products.

5.2.4 Organic carbon and C: N ratio:

Addition of residues low in nitrogen and high in organic carbon make the soil phytotoxic especially to seedlings because of presence of short chain organic acids. Further, there is immobilization of inorganic nitrogen of the soil and other nutrients also become non-available to plants due to activities of heterotrophic bacteria (Brady and Weil, 2002). But vermicomposting converts such imbalanced residues into soil supplements in a short span of time (Domínguez et al., 1997). There was a positive correlation in OC content of the products with the concentration of beverage, paper and distillery industry sludge in the mixtures. Percent decline over initial in organic carbon of the products of vermicomposting from 100% beverage, paper and distillery biosludge was respectively 35.9%, 22.8%, and 11.2% more than the respective products of traditional aerobic composting. Decline in organic carbon was observed to be directly correlated with the stocking density of earthworms also as maximum decline was observed in the feed mixtures with 25g *E. fetida*/kg feed for all the sludges. Out of the three sludges decline in OC was observed to be maximum for distillery (40.9%) followed by pulp and paper mill (32.1%) and beverage sludge (23.8%). Higher decline in organic carbon during vermicomposting may be due to the combined activity of earthworms and microbes. This gets corroborated by the findings of Tognetti et al. (2007a) that the rate of CO2 production from vermicompost piles was much higher than the traditional aerobic compost piles. Higher loss of carbon during vermicomposting could also be due to a higher rate of mineralization by the catabolically active microbes promoted by the worms in the piles (Aira et al., 2007, Prakash and Karmegam, 2010).
The decline in C: N ratio of the products of vermicomposting was brought about by a simultaneous decline in organic carbon and an increase in nitrogen of all the mixtures. In the present study the bio sludge from beverage, paper mill and distillery industry possessed C: N ratio in the range of 28.5:1, 84.9:1 and 30.63:1 respectively, which is much higher than the recommended range for take up by the plants. But co-composting with cattle dung resulted in a lower C: N ratio of the products from the mixtures, which hints towards faster stabilization and improvement in the quality of the products of both the technologies. Higher decline in C: N ratio in the products of vermicomposting in comparison to the products of traditional aerobic composting highlights importance of vermicomposting over the conventional methods. Stabilization of various mixtures of the three sludges with the help of *Ei. fetida* produced the end product within three to four months with a C: N ratio of 17.6:1, 43.9:1 and 24.1:1 from 100% beverage, paper and distillery industry sludge respectively. With traditional aerobic composting there was an increase in the C: N ratio of the products of 100% beverage sludge while there was distillery decline in C: N ratio of the products of 100% pulp and paper mill and distillery sludge. The decline in C: N ratio was 30.8:1, 78.0:1 and 30:1:1 for 100% beverage, paper and distillery industry respectively at the end of the experiment. This clearly indicates that worms brought about a fastest stabilization of beverage sludge followed by distillery and pulp and paper mill sludge because a decline in C: N ratio to less than 20 indicates an advanced degree of organic matter stabilization and reflects a satisfactory degree of maturity of organic wastes (Senesi, 1989; Morais and Queda, 2003; Sen and Chandra, 2007). Faster decline in C: N ratio (from 17.92 to 10.15%) as compared to composting without earthworm has also been observed by Cabrera *et al.* (2005). Less decline in the C: N ratio of the products of traditional aerobic composting was due to lesser decline in carbon along with a decline in nitrogen content of the products. Actually faster mineralization by microbes in the presence of worms (Elvira *et al.*, 1996) may be responsible for higher decline in C: N ratio over initial during vermicomposting in comparison to the products of traditional composting. Optimum range of C: N ratio recognized for an arable soil varies from 8:1 to 15:1 and its maintenance is constrained by soil nitrogen level. This clearly indicates that there will be beneficial effect of the products of vermicomposting of the selected three sludges on the soil in comparison to the products of traditional composting. In the second phase of experiment decline in C:N ratio was maximum in BE$_2$ (32.51%) and B’E$_2$ (26.16%) for beverage, PE$_2$ (59.9%) and P’E$_2$ (65.7%) for paper, DE$_2$ (49.9%) and D’E$_2$ (47.4%) for distillery
industry. This indicates that weight of *Ei. fetida* (g)/kg feed mixture is a determining factor for the final C: N ration of the products.

### 5.2.5 Phosphorus

The products of vermicomposting had higher phosphorus content in comparison to the products of traditional aerobic composting. Phosphorus showed a positive correlation with the proportion of beverage and distillery sludge but had a negative correlation with the proportion of paper mill sludge in the feed mixtures. Maximum increase in the content of phosphorus over initial was observed in BV$_2$ of beverage biosludge (52.3%) followed by PV$_2$ (41.8%) of paper mill and DV$_4$ (13.8%) of distillery sludge. Traditional aerobic composting brought a decline in phosphorus content of the products and the decline was maximum in PV$_1$ (10.0%) and minimum in DV$_6$ (2.6%). This clearly indicates that activity of earthworms, in addition to microbial activity enhances availability of phosphorus from such industrial sludges. This gets corroborated by the findings of Krishnamoorthy, (1990), Patron *et al.* (1999), Kaviraj and Sharma (2003), Tognetti *et al.* (2005) and Liu and Price (2011) who observed stimulating effect of earthworms on the availability of phosphorus in soil. The rise in phosphate content of vermicompost has been attributed to the presence of alkaline phosphatases in the worm casts (Bayon and Binet, 2006; Prakash and Karmegam, 2010). IIImer *et al.* (1995), Vinotha *et al.* (2000) and Kumar and Singh (2001) also reported that a large fraction of soil phosphorus in mineral form and not readily available for plants was made available by phosphate solubilising microorganisms in the presence of worms. In the second phase of the present experiment importance of the optimum weight of earthworms per kg feed became more evident as maximum increase in phosphorus was noticed with 12.5 g *Ei. fetida*/kg mixture 59.2% in PE$_2$, 55.7% in DE$_2$ and 38.6% in BE$_2$ and it was less with 7.5g and 25g *Ei. fetida*/kg mixture.

### 5.2.6 Potassium

Potassium declined in all the products of vermicomposting (during both the phases of the present study), while it increased in the products of traditional aerobic composting. The content of potassium, however, showed a negative correlation with the concentration of biosludge in the mixtures of the three industrial sludges of the present study. Decline in potassium was maximum in BV$_5$ (58.1%) of beverage biosludge followed by DV$_2$ (38.4%) of distillery sludge and PV$_3$ (31.8%) of paper mill sludge during phase I. In the second phase decline in potassium was
positively correlated with earthworm density as it was maximum in \( \text{BE}_3 \) (44.4\%) of beverage sludge, \( \text{PE}_3 \) (14.0\%) of paper mill sludge and in \( \text{D’E}_3 \) (14.1\%) of distillery sludge. Rise in pH of the mixtures during vermicomposting may be responsible for decline in potassium as higher pH makes potassium ions more susceptible to fixation by colloids (Alexander, 1983; Brady and Weil, 2002). Orozco et al. (1996), Benitez et al. (1999), Garg et al. (2006) and Kumar et al. (2010) attributed the decline in potassium to leaching during vermicomposting but the present system was a closed system so it seems that earthworms use the available potassium as it was more in the products of all the corresponding mixtures of traditional aerobic composting. However, Delgado et al. (1995), Suthar (2008) and Liu and Price (2011) reported higher potassium content in the vermicompost produced from the different feed mixtures.

5.2.7 Sodium:

Vermicomposting brought an increase in sodium in the products of beverage and distillery sludge except for PV5 of paper mill sludge. Sodium showed a positive correlation with the concentration of biosludge in the mixtures for beverage and paper mill but a negative correlation with distillery sludge in the feed mixtures. With an increase in weight of earthworms/kg mixture a corresponding increase in sodium over initial was observed in all the products. Maximum increase in sodium was noticed in \( \text{BE}_2 \) (61.4\%), \( \text{PE}_2 \) (55.7\%) and \( \text{D’E}_2 \) (38.7\%) of beverage, paper and distillery sludge. Yadav and Garg (2011) also reported an increase in sodium contents in the final products of vermicomposting of vegetable wastes and attributed the variation in the sodium content to the differences in the initial quality of the feed substrate.

5.2.8 Transition metals:

Earthworms can store and redistribute heavy metals especially Cu and Zn in the body and in turn lead to a balance between their uptake and excretion which helps them to survive to certain extent in metal contaminated soil (Kizilkaya, 2005; Malley et al., 2006). In the first phase of the present experiment transition metals increased in the final products of both vermicomposting and traditional aerobic composting but the increase was more in the products of vermicomposting. During vermicomposting increase for Cu was maximum in \( \text{DV}_1 \) (20.6\%) of distillery sludge, followed by \( \text{BV}_1 \) (20.4\%) of beverage sludge and \( \text{PV}_5 \) (14.7\%) of paper mill sludge. Increase in the content of Mn was 28.4\% in \( \text{BV}_5 \) of beverage sludge, 28.1\% in \( \text{PV}_5 \) of
paper mill sludge and 28.0% in DV6 of distillery sludge. Increase for Fe was 127.9% in BV2 of beverage sludge, 14.5% in PV1 of paper mill sludge and 10.0% in DV5 of distillery sludge. Content of Zn showed an increase of 27.4% in PV3 of paper mill sludge, 26.6% in BV3 of beverage sludge and 19.7% in DV4 of distillery sludge. More increase in the contents of transition metals in the products of vermicomposting during first phase of the present study can be explained by the fact that organic matter was being reduced at a higher rate after passage through the gut of worms, therefore a higher decrease over initial in weight per unit volume of the vermicompost as compared to the products of traditional aerobic composting could have brought more increase in the contents of transition metals (Kaushik and Garg, 2004; Deolalikar et al., 2005; Kaur et al., 2010; Singh et al., 2010). Kaushik and Garg (2004), Nahru1 Hayawin et al. (2010) and Garg and Gupta (2011) also observed an increase in the content of transition metals in the products of vermicomposting from various organic wastes.

In the second phase of the present experiment, decrease in the contents of transition metals corresponded with an increase in stocking density of earthworms, however, their contents increased in the corresponding products of traditional aerobic composting. Maximum decrease in transition metals was noticed in the feed mixtures having 25.0 g worms/kg feed for all the sludges. Decrease for Cu was 78.0% in PE3 of paper mill sludge, 42.7% in B’E3 of beverage sludge and 40.0% in DE3 of distillery sludge. Decrease for Mn was 41.2% in D’E3 of distillery sludge, 18.4% in P’E3 of paper sludge and 16.8% in B’E3 of beverage sludge. Decrease for Fe was maximum in D’E3 (47.2%) of distillery sludge, followed by B’E3 (23.4%) of beverage sludge and PE3 (10.8%) of paper mill sludge. Decrease for Zn was 37.6% in BE3 of beverage sludge, 32.4% in D’E3 of distillery sludge and 19.2% in P’E3 of paper mill sludge. Variable decline in the contents of transition metals in the products may be due to the fact that earthworms accumulate heavy metals in the cells of their yellow tissue and there is a variation in the binding of metals with the ligands of these tissues that leads to a variable bioaccumulation of various metals in the tissues (Fischer and Molnar, 1992; Tavers and Carvalho, 1992; Suthar et al., 2008). Lukkari et al. (2004) observed a positive correlation between metal concentrations in the earthworms and the soils, further Lukkari et al. (2006) correlated the differences in bioaccumulation factors for different metals, to a variable binding capacity of the ligands for various metals as well as to variable metabolic requirement of earthworms.
5.3 Industrial Effluents

Glass columns (38 x 3.2 cm) filled with 50g vermicompost were used for bioremediation of the effluents of the three industries. It was planned because contents of transition metals in the three effluents were 0.13 to 0.45 mg/l for Cu, 0.12 to 3.4 mg/l for Mn, 15.7 to 20.9 mg/l for Fe and 3.5 to 5.6 mg/l for Zn and their BOD and COD values were very high. Vermicompost proved to be a good biofiltering agent with a great buffering capacity as pH of the effluents came to be neutral. Findings of the present research are corroborated by the findings of Hughes et al. (2007) that the buffering capacity of a vermicompost-manure media was high and pH of the waste water flowing through the reactor declined at increasing bed depth and was probably the result of NH$_4$ oxidation. There was a marked decline in BOD and COD of the effluents on their passage through the columns. The mean reactor effluent COD concentration over the whole trial period was 440.0 mg/l in beverage industry effluent, 530.0 mg/l in pulp and paper industry effluent and 18000.0 mg/l in distillery effluent. These values were 2.5 times less than their respective initial values. The results showed that COD leached from the solid organic wastes at the reactor surface and was gradually removed from the effluent on its passage through the vermicompost column. Gonzalez-Martinez et al. (2007) reported that the highest removal of total and dissolved COD values was 81 and 84% respectively in municipal wastewater. Vermicompost removed the high BOD of the industrial effluents and it came down to 174.0 mg/l from initial 387.5 mg/l for beverage industry, 260.0 mg/l from 440.0 mg/l for paper mill effluent and 5806.0 mg/l from 17200.0 mg/l for distillery effluent. Vermicompost brought a decline in the content of both suspended and dissolved solids of the effluents. TDS and TSS of the effluents respectively came down to 72.0 and 246.0 mg/l for beverage effluent, 210.0 and 230.0 mg/l for paper mill effluent and 206.7 and 105.7 mg/l for distillery effluent. Electrical conductivity of the industrial effluents increased when these were passed through the vermicompost filter and it came to be 4.0 mS/cm from the initial value of 2.0 mS/cm (beverage), 6.1 mS/cm from the initial value of 4.8 mS/cm (pulp and paper mill) and 8.1 mS/cm from initial value of 6.9 mS/cm for distillery effluent.

Heavy metals are toxic even in the minute quantities and it is recommended that no metal should exceed the limit of 3 mg/l in the effluent (Yadav and Garg, 2010). Transition metals declined significantly over initial (p< 0.05) after filtration and showed a positive correlation with
the increasing amount of adsorption material. Vermicompost has high Cation Exchange Capacity (CEC), high humidity content, wide particle size distribution, high concentration of nutrients and a characteristic black colour due to the presence of humic substances (Rashid, 1974). Ability of the vermicompost to bind metals has largely been attributed to the presence of negatively charged functional groups (Masini et al., 1998). Maximum adsorption was noticed for Cu for the three industrial effluents of the present study whereas adsorption of Zn was much less from beverage and paper mill effluent in comparison to distillery effluent. This may be due to the difference in pH values of these effluents as the most important parameter influencing the adsorption rate and capacity is pH (Jordao et al., 2007). Humic substances, one of the main components of the vermicompost are responsible for metal adsorption (Matos and Arruda, 2003; Pereira and Arruda, 2003) and are made up of a number of organic compounds with complex molecular structure (aromatic rings, carbonyl groups, phenolic and alcoholic hydroxyl) which bind with different metal ions. These substances are formed by chemical and microbial decomposition of animal and plant materials (Landgraf et al., 1998). Humic acids precipitate at acidic and alkaline pH whereas fulvic acids are soluble under both these conditions (Stanley, 1994), this may be the reason for the efficiency of vermicompost for removal of heavy metals from the effluents with a variable pH in the present study.

Waste reduction by recycling is an important part of any integrated liquid waste management system because industries have to spend a lot on the disposal of the sludge and treatment of the effluents. This study shows that vermicomposting of industrial sludges on mixing with cattle dung can solve the problem of disposal of these organic wastes with high quantities of nutrients locked in them. The organic sludges of the three industries of the present study were converted into a soil supplement with better nutrient quality by the joint action of *Ei. fetida* and microbes in a short span of time i.e nearly 90-100 days. It was observed that 50:50, 30:70 and 25:75 ratios respectively of beverage, paper and distillery sludge with cattle dung were best for buildup for population buildup of *Ei. fetida*. Increase in nitrogen, phosphorous, minor elements along with a faster decline in organic carbon and C: N ratio of the products of vermicomposting in comparison to that of traditional aerobic composting suggests that this technology is a better option for bioremediation of imbalanced sludges over traditional aerobic composting. Increasing stocking density of *Ei. fetida*/kg mixture enhanced rate of degradation.
but best quality products were obtained with 12.5 g worms/kg mixture. Contents of transition metals were lower than International standards for manures, so this compost can be used in the fields without any ill effects. This study also shows that vermicompost can be used efficiently as a filter for bioremediation of a wide variety of effluents. By using this combined technology industries will not only save money on the disposal of their wastes but will also help in conservation of our natural resources.