VOL. 8, NO. 10, OCTOBER 2013 ISSN 1990-6145
ARPN Journal of Agricultural and Biological Science

www.arpnjournals.com

ENVIRONMENTAL IMPACT ASSESSMENT OF MILK PRODUCTION WITH THE LIFE CYCLE

Prayong Keeratiurai
School of Civil Engineering, Faculty of Engineering, Vongchavalitkul University, Nakhon Ratchasima, Thailand
E-Mail: keeratiurai_pray@windowslive.com

ABSTRACT

The carbon emission of dairy cows and dairy farm co-operatives during milk production was studied to assess the environmental impact of milk production with life cycle in Nakhon Ratchasima province, Thailand. The sampling numbers were 309 dairy farms, 9 dairy farm co-operatives, and 400 dairy cows. The study showed that the kilogram carbon dioxide emission factor per head per day from dairy cows and the energy sectors of farm activities was 9.812 kg.CO_2/head/day and the energy sectors of dairy farm co-operative activities in milk production was 2.017 kg.CO_2/head/day. It was also found that the efficiency of dairy cows that transfer carbon from the first producers and fixed to milk was 10.33% and the ratio of C emission factor was changed from the first producers and energy sectors of dairy production by 0.427. The ratio of carbon contents that were emitted to carbon contents fixed in milk and the growth of dairy cows was 0.757. The dairy wastewater treatment was undertaken with the using of anaerobic fixed film reactor with HRT 1.0, 1.5, 2.0, and 2.5 day on a laboratory scale. The removal efficiencies of COD, BOD_5, TKN, and TP of anaerobic fixed film reactor were 79.15%, 93.55%, 74.00%, and 81.50%, respectively. The total COD and BOD_5 removal efficiency decreased slightly with an increasing in organic loading rate (OLR). Most organic compounds containing carbon is the main component to be easily digested by microorganisms. There was a significant organic removal efficiency of the fixed film system tested in terms of BOD_5 and COD ($p < 0.05$). The major contents of nitrogen constituents in dairy wastewater were organic-nitrogen with 97.5±2.1% and the remaining was nitrate-nitrogen. The ammonia-nitrogen could be monitored at the effluent with the percentage was 67±16%. The contents of dairy wastewater consist of ortho-phosphate and organic-phosphorus with the ranges of 59-69% and 31-41%, respectively. Regarding to the treated wastewater, the minor content was organic-phosphorus. The maximum biogas production rate was $(3.396 \pm 3.19) \times 10^{-3}$ m^3/day at 2.07 kg. COD/m^3/day. In case of biogas composition, the methane was found in the percentage was 70±10%. The 341 L of methane was generated from 1 kg. COD used. As indicated above, the anaerobic fixed film reactor could be used as the pretreatment unit for dairy wastewater including the biogas production.

Keywords: dairy farm cooperative, milk production, dairy cow, EIA, life cycle.

INTRODUCTION

In Thailand there are various non-greenhouse gas issues that also need to be considered when identifying effective and sustainable options for greenhouse gas mitigation. What is required, however, is that mitigation options need to be evaluated in the context of the livestock system before being promoted for adoption, because the consequences for the whole system along with the effects on emissions of carbon dioxide equivalent need to be understood. Dairy cow, ox and buffalo are herbivores that are raised for their milk and meat, however, production of dairy cow and cattle produce emission of both CO_2 and CH_4. The emissions from dairy cows are more than that from other cattle (Keeratiurai, 2012b). One product of carbon fixation is the protein in milk, meat and animal products. The net carbon production is the rate at which carbon is fixed during growth. The net carbon production can be used to explain the time averaged C stocks by carbon weight per time (van Noordwijk, *et al*., 1997 and 1998).

The reduction of emissions of air pollutions is subject of international conventions, which include reporting of emissions in accordance with guidelines or guidebooks provided. With respect to emissions from agricultural sources, in particular from animal husbandry, the calculation procedure making use of partial emission factors for the various sources of emissions (animal house, storage, manure application, etc.) is being replaced by a mass flow concept for carbon species. The way to describe emissions from animal husbandry was to apply a mass flow approach, which depicts the pathways of C species strictly under the aspect of mass conservation (Dämmgen and Webb, 2006).

Simpler methodologies calculate overall emissions in animal husbandry using fixed amounts per animal or animal place where; E is the emission (kg × area^{-1}). For a given number of animals, total emissions are calculated using the sum of the partial emission factors where; n is the number of animals considered and EF is the emission factor (kg × animal^{-1} × area^{-1}). In agriculture, this stresses the need for methods, which go beyond simple calculations of the type:

$$E_{total} = n_{animal} \times (EF_{metabolic} + EF_{grazing} + EF_{housing} + EF_{storage} + EF_{spreading}) \quad (1)$$

Crops produced can serve as animal feed. They are inputs into the animal subsystem. In the animal subsystem, direct metabolic emissions will occur, in particular of CH_4 from enteric fermentation. C excreted are then stored and eventually spread. These flows and the respective emissions are dealt with in the manure management subsystem. Slurry and manure treatments are important measures to reduce emissions (Dämmgen, *et al.*, 2003).

Wastewater of milk production plant was important problem since a large quantity of water was used for product addition and utensil cleaning. Subsequently, approximately 80% of used water was discharged as wastewater, which contains a large amount of milk constituents such as casein, lactose, fat and others. These all contribute towards its high contents of nutrients contained in dairy wastewater, which were the main cause of the deterioration of the quality of receiving water body. The discharged volume of wastewater depends on the size of plant and their activities. The treatment of dairy wastewater with less area requirement should be appropriate.

The focus of this study is on carbon which is transferred to the food chain and emitted in milk production. Therefore it is important to assess the environmental impact of milk production. Approaches that may assist decision makers to identify options for greenhouse mitigation options from livestock systems are discussed.

LCA methodology applied in this study

The Society of Environmental Toxicity and Chemistry are generally credits for the current LCA methodological framework. Recent standard by the International Organization for Standardization have defined LCA as the study related to the environmental aspects and potential impacts throughout the life of products from raw materials acquisition through production, use and disposal (Leng, *et al.*, 2008). The International Organization for Standardization of 14000 series was formed to accept as providing a consensus framework for LCA (Rebitzer, *et al.*, 2004). Inventory analysis involves data collection and calculation procedures to quantify the relevant input and outputs of a product system. These inputs and outputs may include the use of resources and releases to air, water and land associated with the system (Thu Lan, 2007). Life cycle study, data collection represented a time consuming task and it was important to obtain quantitative information concerning various processes in the product system. A significant part of data associated of milk production with life cycle was collected from dairy cow farms and co-operatives. Data for carbon emission, and energy consumption, resources and material were obtained directly from dairy cow farms and co-operatives. A useful instrument facilitating the estimation of gas emissions was the emission factor, which was a representative value attempts to link the associate with the system output. The process of impact assessment analyzes the environmental burdens associated with the material and energy flows determined in the inventory analysis phase though successive steps listed as follow classification, characterization, normalization and weighting (Curran, 1996).

The final phases of LCA were made based on the combination of findings from the inventory analysis and the impact assessment, consistent with the objective and scope definition. The environmental impact potentials in global warming were calculated in this step. This environmental impact in global warming was caused by the emission of green house gases such as CO_2, CH_4, N_2O, and etc. Thanee, *et al.* (2009) concluded that CO_2 emission was 0.18 kg.C/kWh, CO_2 emission from LPG was 3.0102 kg.CO_2 eq./1kg.LPG, CO_2 emission from diesel oil was 0.61 kg.C/L and CO_2 emission from gasoline was 0.57 kg.C/L, and Keeratiurai (2012a) have suggested CO_2 emission was 74.5 kg.CO_2/1 Ton/500 km.

The calculations were carried out with the equation given below. The potential environment impacts were calculated as follows (Thu Lan, 2007).

$$\Sigma EP_i = \Sigma Q_i \times EF \qquad (2)$$

Where

EP_i = The emission potential contribution to the environment impact
Q_i = The magnitude of emission of substance
EF = The substance's equivalency factor for the environmental impact category

METHODOLOGY

The study of environmental impact of milk production with life cycle was shown in Figure-1.

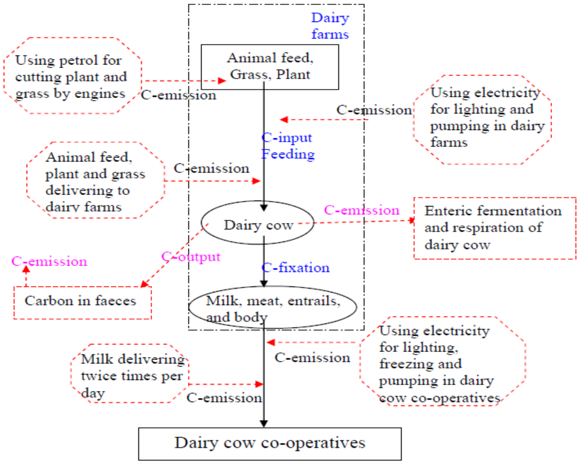

Figure-1. Life cycle assessment to evaluate CO_2 emission for the milk production.

Size of samples, site sampling methods and analytical methods

The data of Johnson *et al.* (2002) showing the relative contribution of these sources from the contrasting situations of Wisconsin and New Zealand dairy farms, indicate that the type of production system can have a major impact on the relative importance of each source. We studied dairy farms and dairy cow co-operatives, in 32 districts of Nakhon Ratchasima province. Nakhon Ratchasima province has an agricultural area of 12, 469.46 square kilometers which is the largest area of dairy farms in Thailand (Center for Agricultural Information, 2004). The numbers of farms, dairy cows in each district were calculated by determining the number of dairy farms, dairy cow co-operatives and the number of dairy cows in the province at 95% confidence level (Cavana, *et al*., 2000). Therefore, the sample groups were calculated by Taro Yamane's formula (Yamane, 1973) as follows;

$$n = \frac{N}{1 + Ne^2} \qquad (3)$$

Where

n = Sample size
n = Population size
e = The error of sampling

The sampling numbers were 309 dairy farms, 9 dairy farm co-operatives, and 400 dairy cows. Grass and foods for dairy cows, milk and faeces of dairy cows were collected and transferred to the laboratory at Vongchavalitkul University. The analytical methods are shown in Table-1.

Table-1. Methods for property analysis of animal feed, milk, gases and faeces from dairy cows.

Properties	Analytical methods	References
Moisture content	By weighing sample after oven drying at 103-105 °C for 24 hours	Manlay *et al*. (2004)
Carbon content (C)	By CNS-2000 elemental analyzer and gas analyzer	Manlay *et al*. (2004)
Volatile and fixed solids	By weighing the known weight of the sample after burning at 550°C for 30 minutes	APHA, AWWA, WEF. (1992)
Weight of dairy cow	By weighing or using a cattle weighing tape	Bunyavejchewin *et al*. (1985), Vudhipanee *et al*. (2002)

Equipment used in operations research

Anaerobic fixed film reactor (AFFR) was attempted to achieve contact between microorganism and nutrients or sewage sludge by bio-media and circulate of wastewater sludge in system. Anaerobic fixed film include reactor has 880 liters in a cylindrical shape, 75cm in diameter, and 2 meters high as shown in Figure-2. By an anaerobic fixed film reactor, the components are as follows:

- Circulation pumps in the sewage sludge in the anaerobic fixed film reactor
- Bio-media to make contact, with surface of 240 square meters per cubic meter
- Section for exhaust biogas of anaerobic reactor

The system went into steady state. The percentage average of COD removal in 10 days had standard deviation less than 10%. The collected wastewater samples at inlet and outlet of anaerobic fixed film reactor. The parameters were analyzed of the Standard method.

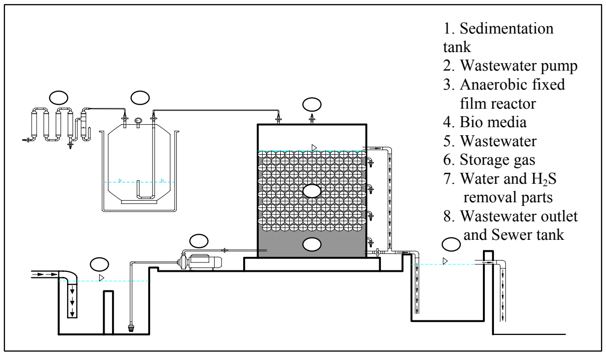

Figure-2. Section of anaerobic fixed film reactor.

Statistical data analysis

The data are analyzed with descriptive statistics and statistical analysis as follows:

a) To describe the characteristics of the wastewater, performance of anaerobic fixed film reactor and the amount of gases each day in mean, standard deviation, and percentages of efficiency.
b) Performance testing of the anaerobic fixed film reactor and the difference of before and after treatment of the Temperature, pH, TKN, TP, TS, SS, VSS, TDS, COD, BOD5, and amount of energy in various forms used in the milk production were tested at 95% confidence level.

$$\% \text{ Removal efficiency} = \frac{(in - out)}{in} \times 100 \qquad (4)$$

c) Evaluation of the emission of greenhouse gases such as CO_2 and CH_4 in various forms of energy used to produce milk, wastewater treatment and biogas production.

RESULTS AND DISCUSSIONS

The results showed that the average milk production from dairy cows was 11.144±2.70 kg./head/day, the average weight of faeces 18.85±3.41 kg./head/day from the average weight of dairy cow was 449.19±53.99 kg./head and the C emission factor was 11.810 kg.CO_2/head/day. The ratio of faeces of dairy cow to weight of dairy cow was 4.2% and the ratio of milk to weight of dairy cow was 2.48%.

The C emission factor and the rate of change in carbon contents

This study showed that the carbon content was emitted from activities in dairy cow sectors. The C emission factor was 9.812 kg.CO_2/head/day. The CO, CO_2, and CH_4 gases which were emitted from faeces were 0.000±0.000 kg.CO/head/day, 0.110±0.022 kg.CO_2/head/day, and 0.004±0.001 kg.CH_4/head/day, respectively. The CO, CO_2, and CH_4 gases which were emitted from enteric fermentation and respiration of dairy cow were 0.001±0.000 kg.CO/head/day, 2.211±0.459 kg.CO_2/head/day, and 0.123±0.037 kg.CH_4/head/day, respectively. The carbon contents emitted, to influence the environmental problem, was 38.60%.

The carbon contents of energy sectors for milk production

The dairy farms, that are members of dairy farm co-operatives, used 3 energy sectors for milk production. The first sector was the electricity energy for lighting and pumping of milk. The second sector was petrol used for transporting milk to dairy farm co-operatives daily. The last was petrol used for cutting grass and transferring it to the farms for feeding. The CO_2 emission per unit of three energy sectors of dairy farm was 0.755 kg.CO_2/head/day. The dairy farm co-operatives used electricity for milk cooling and for transporting milk from dairy farm co-operatives to dairy manufactory. The CO_2 emission per unit of electricity and petrol used by dairy farm co-operatives was 1.243 kg.CO_2/head/day. The results of the carbon contents per unit in the energy sectors for milk production were shown in Table-2.

Table-2. The averages of CO_2 emission from energy sectors of dairy farms and dairy farm co-operatives.

Average carbon contents from energy sectors (kg.CO_2/head/day)	**CO_2 emission**	
	Dairy farms	**Dairy farm co-operatives**
Electricity	0.293	0.357
Transportation energy	0.037	0.887
Engine energy	0.425	-

The transportation energy and the engine energy of the dairy farms had CO_2.eq.emission of 83.33% and 84.67% of C_{input}, respectively. The transportation energy of the dairy farm co-operatives had CO_2.eq.emission of 84.91% of C_{input}. The sum of the total CO_2 emission per unit from the electricity energy and the transportation and engine energy of dairy farms and dairy farm co-operatives was 1.998 kg.CO_2/head/day. The transportation and engine energy had carbon loses of 0.242 kg.CO_2/head/day. This CO_2 emission showed the environmental problems known as global climate changes from the energy sectors in milk production. Also the ratio of C emission factor emitted to carbon contents was changed from producers and energy sectors of dairy production was 0.427 and the ratio of carbon contents were emitted to carbon contents were fixed in milk and the growth of dairy cow was 0.757.

The AFFR performance

Characteristic of dairy wastewater, including Temperature, pH, TKN, TP, TS, SS, VSS, TDS, COD, BOD_5 of wastewater inputs to the system and wastewater out of the system, and volume of biogases were analyzed by standard method. The results of the analysis of wastewater inputs to the system from the laboratory were shown in Table-3.

Table-3. The Characteristics of dairy wastewater used to AFFR.

Parameters	Unit	Average ± S.D.
Temp.	ºC	30±2
pH	-	6.4±1.1
TKN	mg/L	22.8±4.43
TP	mg/L	1.15±0.69
TS	mg/L	915±160
SS	mg/L	208.5±81.5
VSS	mg/L	208±152
TDS	mg/L	736.5±211.5
COD	mg/L	932.67±79.67
BOD_5	mg/L	695±110

The dairy cow wastewater was treated using the anaerobic fixed film technology on hydraulic retention time (HRT) 1.0, 1.5, 2.0, 2.5 day to provide an overview of this study. There was a significant solid removal efficiency of the fixed film system tested in terms of SS, TS, VSS, and TDS ($p < 0.05$) as shown in Figure-3. Suspended solids can cause turbidity in water, affect the growth and propagation of aquatic species.

The pH values of effluent were in the ranges of 6.8-7.2 with the temperature of 28ºC-31ºC. These ranges of pH value did not have any effects to the performance of AFFR. In the other hand, they provide the optimum condition for acidogenesis bacteria and methanogens. The organic compound in AFFR or anaerobic condition was assumed to be converted to organic acids and later to acetic acid, and finally to methane and carbon dioxide gas. Volumetric biogas production rate increased slightly linearly with the COD loading rate, until reaching a maximum 6.586×10^{-3} m^3/day at 2.07 kg.COD/m^3/day as shown in Figure-4. In case of biogas composition, the methane was found in the percentage was 70±10%. The 341 L of methane was generated from 1 kg. COD used. This value was slightly inferior to the stoichiometric theoretical of 0.35 m^3CH_4/kg.COD and similar to the result studied by Perez *et al*. (2001), 0.33 m^3CH_4/kg.COD.

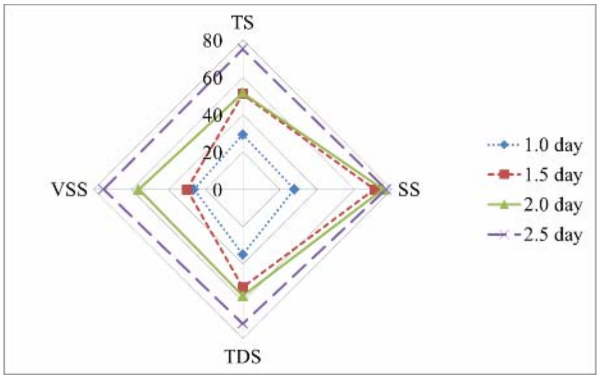

Figure-3. The solid removal efficiency on HRT of anaerobic fixed film reactor.

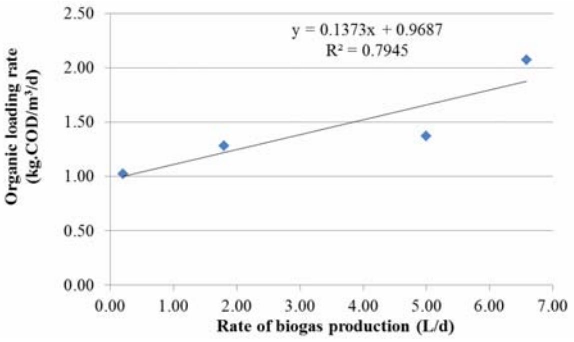

Figure-4. The relation between OLR and biogas production of anaerobic fixed film reactor.

The total COD removals of 1.0, 1.5, 2.0, 2.5 day hydraulics retention times were in the ranges of 76.0 to 92.3% as shown in Figure-5. The COD removal efficiency of 2.5 day HRT was slightly higher than that of 2.0 day and slightly decreased at 1.5 day. In this study, they could be observed that total COD removal was clearly dropped at 1.0 day HRT due to the increase of upflow velocity and organic loading rates. The upflow velocity was the main limiting factor for design of AFFR for treated dairy wastewater. The total COD removal efficiency decreased slightly with an increasing in organic loading rate (OLR). The removal efficiencies were in the ranges of 92.3-90.1% for 1.02 to 1.37 kg.COD/m^3/day. Whereas the removal efficiency of total COD at the OLR of 2.07 kg.COD/m^3/day was sharply decreased to be 76.0 as shown in Figure-6. Panesar *et al*. (1999) reported that at the one point of increased OLR for a UASB reactor treating dairy wastewater, reduced performance was observed. The removal efficiencies of BOD_5 were in the ranges of 85.1 to 97.0%, the maximum efficiency was observed in 2.5 day HRT. The high efficiency of BOD_5 removal was obtained from this AFFR since the soluble organic matter in dairy wastewater could be easily degraded by microorganisms containing in reactor.

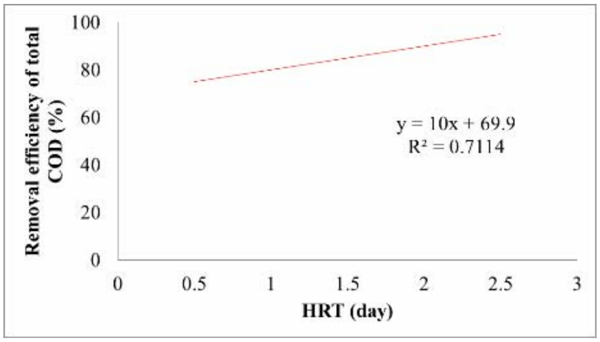

Figure-5. The removal efficiencies of total COD at any HRTs.

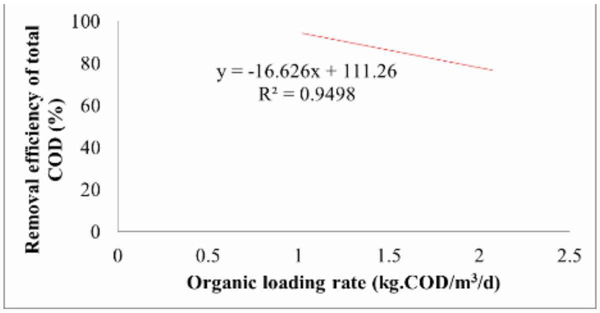

Figure-6. The relation between OLR and total COD removal efficiencies of anaerobic fixed film reactor.

The major contents of nitrogen constituents in dairy wastewater were organic-nitrogen with 97.5±2.1% and the remaining was nitrate-nitrogen. The ammonia-nitrogen in the influent was not found for all HRTs; whereas it could be monitored at the effluent with the percentage was 67±16%. Almost of organic-nitrogen in dairy wastewater were converted to ammonia-nitrogen due to bacterial composition and hydrolysis as shown in reaction and later assimilate to organic-nitrogen in bacterial cells.

Organic-nitrogen in dairy wastewater + bacteria→NH_3

Moreover, organic-nitrogen in bacterial cells was also converted to ammonia-nitrogen according to the death and hydrolysis of cell. Regarding to nitrate-nitrogen, it was reduced to nitrite-nitrogen form and later assimilative reduced to ammonia-nitrogen as so-called ammonification by the action of bacteria under anaerobic condition as shown in chemical reaction. Some nitrite-nitrogen was reduced to nitrogen gas due to denitrification reaction.

NO_3^- (reduction) → NO_2^- (assimilate reduction) → NH_3

The contents of dairy wastewater consist of ortho-phosphate and organic-phosphorus with the ranges of 59-69% and 31-41%, respectively. Regarding to the treated wastewater, the minor content was organic-phosphorus. It could be concluded that organic-phosphorus was converted to ortho-phosphate in acid digestion step and some organic-phosphorus were used by microorganisms for cell synthesis and energy transport. Phosphorus was not only utilized by microorganism for cell maintenance, synthesis, and energy transport but also stored for subsequent use (Metcalf and eddy, 1991).

CONCLUSIONS

The study showed that the average milk production from dairy cows was 11.144±2.70 kg./head/day, the average weight of faeces 18.85±3.41 kg./head/day from the average weight of dairy cow was 449.19±53.99 kg. /head and the C emission factor was 11.810 kg.CO_2/head/day. The ratio of faeces of dairy cow to weight of dairy cow was 4.2% and the ratio of milk to weight of dairy cow was 2.48%. The carbon contents emitted, to influence the environmental problem, was 38.60%. Also the ratio of C emission factor emitted to carbon contents was changed from producers and energy sectors of dairy production was 0.427 and the ratio of carbon contents were emitted to carbon contents were fixed in milk and the growth of dairy cow was 0.757. There was a significant solid removal efficiency of the fixed film system tested in terms of SS, TS, VSS, and TDS ($p < 0.05$). Volumetric biogas production rate increased slightly linearly with the COD loading rate, until reaching a maximum 6.586×10^{-3} m^3/day at 2.07 kg.COD/m^3/day. The methane was found in the percentage was 70±10%. The 341 L of methane was generated from 1 kg. COD used. The total COD removals were in the ranges of 76.0 to 92.3%. The total COD removal efficiency decreased slightly with an increasing in organic loading rate (OLR). The removal efficiencies were in the ranges of 92.3-90.1% for 1.02 to 1.37 kg.COD/m^3/day. The high efficiency of BOD_5 removal was obtained from this AFFR since the soluble organic matter in dairy wastewater could be easily degraded by microorganisms containing in reactor. The major contents of nitrogen constituents in dairy wastewater were organic-nitrogen with 97.5±2.1% and the remaining was nitrate-nitrogen. The ammonia-nitrogen in the influent was not found for all HRTs; whereas it could be monitored at the effluent with the percentage was 67±16%. The contents of dairy wastewater consist of ortho-phosphate and organic-phosphorus with the ranges of 59-69% and 31-41%, respectively. Regarding to the treated wastewater, the minor content was organic-phosphorus.

REFERENCES

APHA AWWA WEF. 1992. Standard Methods for the Examination of Water and Wastewater. 18th Edition. Wash. D.C., USA. American Public Health Association.

Bunyavejchewin P., Rompopak W., Vechabusakorn O., Khumnerdpetch W., Pikulthong P. and Chantalakhana C. 1985. Comparative Efficiency of Tapes for Estimation of Weight of Swamp Buffaloes and Cattle. Annual Report 1985. The National Buffalo Research and Development Center Project. Bangkok, Thailand.

Cavana R. Y., Delahaye B. L. and Sekaran U. 2000. Applied Business Research: Qualitative and Quantitative Methods. New York: John Wiley and Sons.

Center for Agricultural Information, Office of Agricultural Economics. 2004. Agricultural Statistics of Thailand 2004. Agricultural Statistics No. 410. Ministry of Agriculture and Co-operatives. Bangkok, Thailand.

Curran M. A. 1996. Environmental Life-Cycle Assessment. McGraw-Hill Companies Inc, USA.

Dämmgen U., Menzi. H. and Webb J. 2003. Background on ammonia (and other gaseous) emissions from agriculture: UNECE CLRTAP Task Force on Emission Inventories and Projections Agriculture and Nature Panel [On-line]. Available: http://air-climate.eionet.eu.int/docs/meetings/030227_AgricEmiss/3_Backgrnd_Agric_Em_NH3_Ulrich_Daemmgen.pdf. Accessed date: March 2007.

Dämmgen U. and Webb J. 2006. The development of the EMEP/CORINAIR Guidebook with respect to the emissions of different nitrogen and carbon species from animal production. Agriculture, Ecosystems and Environment. 112: 241-248.

Johnson D.E., Phetteplace H.W. and Seidl A.F. 2002. Methane, nitrous oxide and carbon dioxide emissions from ruminant livestock production systems. In: Greenhouse gases and animal agriculture. Proceeding of the 1st International Conference on Greenhouse Gases and Animal Agriculture, Obihiro, Japan, November 2001. J. Takahashi and B.A.Young (Eds.). pp. 77-85.

Keeratiurai P. 2012a. Carbon Footprint of Tapioca Starch Production using Life Cycle Assessment in Thailand. European Journal of Scientific Research. 77(2): 293-302.

Keeratiurai P. 2012b. Comparison of C Massflow of Oxen and Dairy Cows in Meat and Milk Production. European Journal of Scientific Research. 81(4): 493-501.

Leng R., Wnag C., Zhang C., Dai D. and Pu G. 2008. Life cycle inventory and energy analysis of cassava-based Fuel ethanol in China. Cleaner Production Academic Publisher. pp. 374-384.

Manlay Raphaël J., Ickowicz Alexandre, Masse Dominique, Floret Christian, Richard Didier and Feller Christian. 2004. Spatial carbon, nitrogen and phosphorus budget of a village in the West African savanna-I. Element pools and structure of a mixed-farming system. Agricultural Systems. 79: 55-81.

Manlay Raphaël J., Ickowicz Alexandre, Masse Dominique, Feller Christian and Richard Didier. 2004. Spatial carbon, nitrogen and phosphorus budget in a village of the West African savanna-II. Element flows and functioning of a mixed-farming system. Agricultural Systems. 79: 83-107.

Metcalf and Eddy Inc. 1991. Wastewater Engineering Treatment, Disposal, and Reuse. 3rd Edition. Singapore. McGraw-Hill International Editions.

Moe P.W. and Tyrell H.F. 1979. Methane Production in Dairy Cows. Journal of Dairy Science. 62(10): 1583-1586.

Panesar P.S., Rai R. and Marwaha S.S. 1999. Biological Treatment of Dairy Industry Effluents. Asian Journal of Microbiology Biotechnology and Environmental Science. 1(1-2): 67-72.

Perez M., Romero L.I. and Sales D. 2001. Organic Matter Degradation Kinetics in an Anaerobic Thermophilic Fluidised Bed Bioreactor. Anaerobe. 7: 25-35.

Rebitzer G., *et al*. 2004. Review Life cycle assessment. Part 1: Framework, goal, and scope definition, inventory analysis, and application. Environmental International Academic Publishers. pp. 701-720.

Thanee N., Dankitikul W. and Keeratiurai P. 2009. Comparison of carbon emitted from ox, buffalo, pig, and chicken farms and slaughterhouses in meat production. Suranaree Journal of Science and Technology. 16(2): 79-90.

Thornton P. K., Van de Steeg J., Notenbaert A. and Herrero M. 2009. The impacts of climate change on livestock systems in developing countries: A review of what we know and what we need to know. Agricultural Systems. 101: 113-127.

Thu Lan T. N. 2007. Life cycle assessment of bio-ethanol as an alternative transportation fuel in Thailand.

Van Noordwijk M., Cerri C., Woomer P. L., Nugroho K. and Bernoux M. 1997. Soil carbon dynamics in the humid tropical forest zone. Geoderma. 79: 187-225.

Van Noordwijk M., Murdiyarso D., Hairiah K., Wasrin U. R., Rachman A. and Tomich T. P. 1998. Forest soil under alternatives to slash and burn agriculture in Sumatra, Indonesia. In: A. Schulte and D. Ruhiyat (Eds.). Soils of Tropical Forest Ecosystems: Characteristics, Ecology and Management. Berlin: Springer-Veriag. pp. 175-185.

Vudhipanee P., Lortae K. and Imvatana S. 2002. Comparative efficiency of weight prediction equations of swamp buffalo. Animal Husbandry Division: DLD [On-line]. Available from: www.dld.go.th/research-AHD/Webpage/2545/45(3)-0406-147.pdf. Accessed date: June 2007.

Yamane Taro. 1973. Mathematics for Economists: An Elementary Survey. 2nd Ed. New Delhi: Prentice-Hall.