OPEN CELL APPROACH TOWARDS SUSTAINBALE LANDFILL OPERATION IN TROPICAL ASIA

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ABSTRACT

Open dumping is a prevalent municipal solid waste (MSW) disposal in most Asian countries. Upgrading of existing dumpsites to engineered landfill is an important step to minimize pollutant emission to the environment. However, middle and low income countries are still suffering of lack of financial resources and technical facilities to adapt modern disposal system (e.g. sanitary landfilling). This study aims to investigate the open cell landfill operation with water management under the influence of actual tropical climate condition. Four lysimeters were investigated under different operations (OC-1: open cell, OC-2: open cell combine with leachate recirculation, OC-3: open cell of pre-sorted waste combine with leachate recirculation, and CLF: conventional landfill). The influence of leachate recirculation on open cell lysimeters was monitored in terms of leachate generation, leachate characteristics, and settlement variation since July 2005. Due to reduced rainfall from December 2005, leachate recirculation mode was practiced. Results from over nine months period indicated that the specific cumulative COD and TKN load from OC-2 were 37% and 8%, respectively higher than CLF. OC-3 which mainly contained organic fraction of MSW showed the highest cumulative leachate generation, specific cumulative COD load, and settlement rate. Water management by storage, evaporation, and recirculation resulted to 47% reduction in leachate volume for treatment compared with other lysimeters without water management. Leachate recirculation enhances waste stabilization in landfill, and improves leachate quality. Therefore, improving open cell operation in tropical climate by understanding water management was necessary.

INTRODUCTION

The current urban waste generation from several countries in Asia (Bangladesh, Laos PDR, Myanmar, Nepal, and Vietnam) is forecasted to increase by four to six times by the year 2025 (World Bank, 1999). Moreover, the trend of MSW generation in Sri Lanka, India, China, and Thailand is increasing along with the rapid growth of population and industrialization (Visvanathan et al., 2004). Therefore, most Asian countries are facing the accelerated problems of inadequate MSW collection, transportation, and disposal sites. This will eventually create burden to the environment, especially open dumping is the most common MSW disposal in developing countries. In Thailand and India, for example, 70-90% of final disposal sites are open dumps (Visvanathan et al., 2003). Conventional landfills are popular because it is economical and convenient method of solid waste disposal. Generally, it is referred as the “dry-tomb method”. However, the efficiency of protective liners and top cover deteriorates after long period of operation; thereby moisture may penetrate in landfills, allowing biological activity to occur and generates leachate and landfill gas. Therefore, the design and operation of conventional landfill is unsustainable (Komilis et al., 1999). Landfill operation with leachate recirculation system is known as “bioreactor landfill”. This enhances moisture content, accelerates waste biodegradation, and lead to rapid waste stabilization. Leachate recirculation in bioreactor landfill accelerates landfill gas production, waste volume reduction, reduce leachate pollutant load for treatment, and reduce the burden of after care monitoring (Reinhart and Al-Yousfi, 1996). In addition, water management at landfill sites is an important issue especially in tropical countries. Since, the quantity and quality of leachate from landfill is influenced by tropical seasonal variations (Tränkler et al., 2005). Open cell approach can be a suitable option for developing countries because the design and operation does not differ too much from current operational mode of disposal. During rainy season high amount of leachate generated from open cell should be stored and recirculated during dry season to provide moisture in waste. The objective of this study is to investigate the performance of open cell with water management strategies in comparison with conventional landfill.

MATERIALS AND METHODS

Four pilot scale lysimeters were used in this study. Figure 1 illustrates the detail design of lysimeter and Figure 2 presents the operational mode of each lysimeter. MSW collected from Taklong municipality (Thailand) was mainly consist of organic fraction (60%) with an average moisture content of 52% were filled in multi-layers approximately every week until it reached to about 2.4 m height in lysimeters. Unlike with other lysimeters, OC-3 was filled with pre-sorted MSW (biodegradable fraction). The open cell lysimeters (OC-1, OC-2, and OC-3) had 5 cm thick sand cover. The CLF had intermediate cover (15 cm soil layer) and top cover (40 cm drainage layer, 20 cm barrier layer and 10 cm gravel foundation layer). In addition, the compaction density of all open cell lysimeters was 500-580 kg/m^3 and CLF was 740 kg/m^3 (high compaction density was due to the weight of top cover).

Each lysimeter had separate leachate collection tank and leachate storage tank. Figure 3 shows the leachate recirculation system of OC-2 and OC-3. The lysimeter operation commenced during rainy season (July 2005) and leachate generated from OC-2 and OC-3 was pumped and collected into separate storage tanks. During dry season (December 2005), leachate was recirculated on both lysimeters.

RESULTS AND DISCUSSION

<u>Leachate generation</u>

Figure 4 presents the relationship between rainfall and cumulative leachate generation from lysimeters since July 2005 to March 2006. The first period of lysimeter operation was rainy season (July to mid-November 2005). High amount of leachate was generated due to the initial high moisture content of MSW, biological decomposition of waste, and high precipitation during this period. Leachate from all lysimeters significantly increased on September 2005 due to high intensive rainfall (up to 80 mm/day). In addition, leachate recirculation was not applied on OC-2 and OC-3 in this period due to heavy rainfall. OC-3 showed the highest cumulative leachate generation after nine months of operation. This is because OC-3 is filled with organic waste fraction that contains high moisture content and covered with thin sand layer, the resulting compaction density (580 kg/m^3) is relatively lower than CLF. The second period was dry season (December 2005 - March 2006) which appear to have very less or no rainfall. Thus, in this period, less amount of leachate was produced in all lysimeters. The stored leachate from the first period (rainy season) was used to recirculate in OC-2 and OC-3 lysimeters during this period.

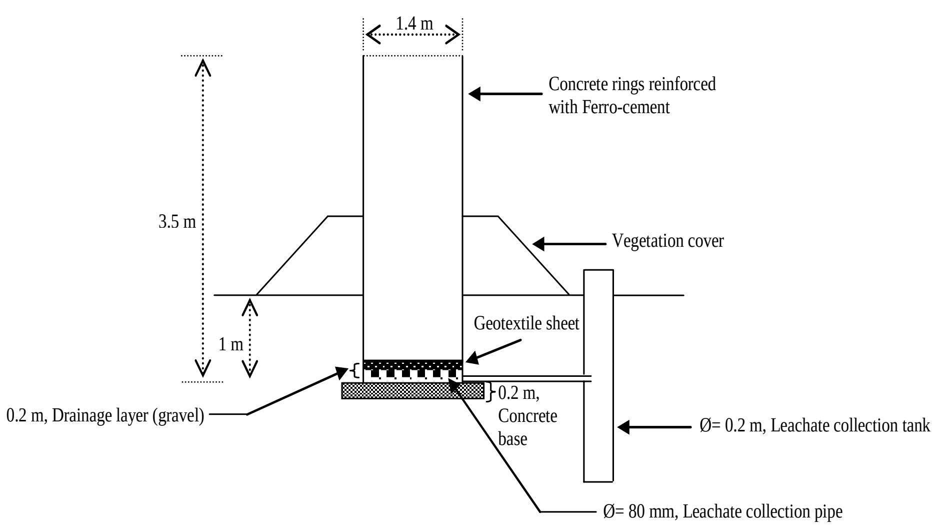

FIGURE 1: PILOT SCALE LYSIMETER DESIGN

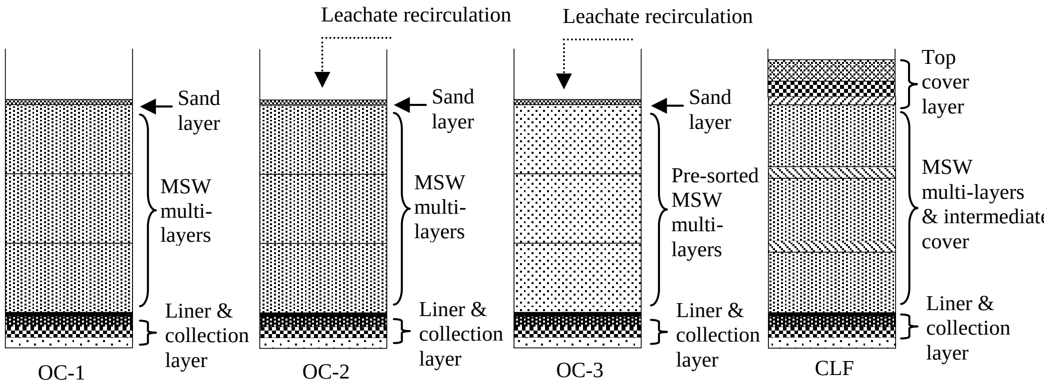

FIGURE 2: DIFFERENT MODE OF LYSIMETER OPERATION

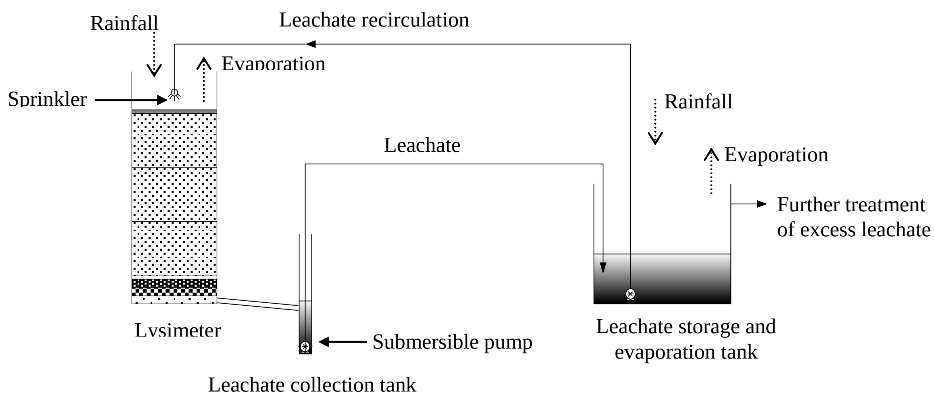

FIGURE 3: MODE OF LEACHATE RECIRCULATION

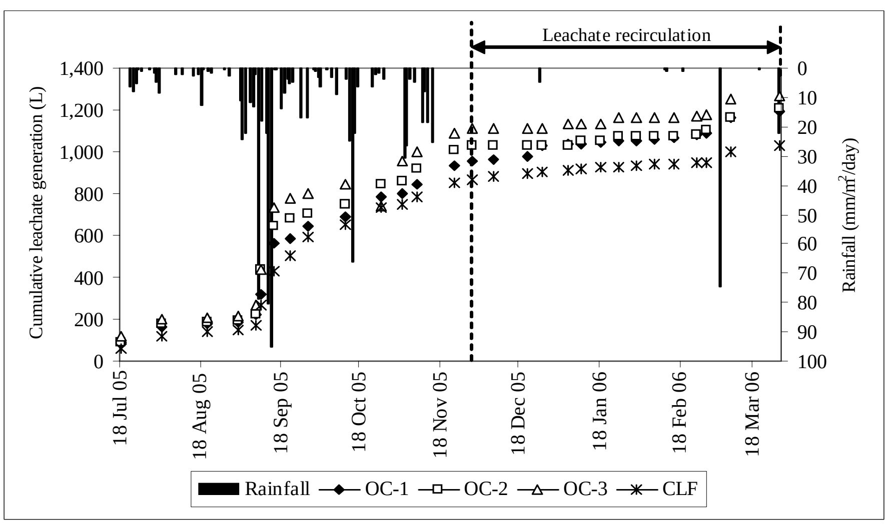

FIGURE 4: RELATIONSHIPS BETWEEN RAINFALL AND CUMULATIVE LEACHATE GENERATION

Leachate characteristics

Leachate quality in terms of pH, COD (chemical oxygen demand), BOD (biochemical oxygen demand), TKN (total kjeldahl nitrogen), specific cumulative COD and TKN load was regularly monitored. The changes of leachate concentration can be used as biodegradation indicator (Yuen, 2001). The pH of all lysimeters gradually increased from initial range of 5.7-6 and stabilized to a value of 7-8 after nine months of operation. At the beginning of operation, the COD concentration of all open cell lysimeters was higher than CLF as a result of high percolation of rainfall that enhanced the leaching out of pollutants. The concentration of COD in leachate gradually decreased with time (Figure 5). Figure 6 shows the COD concentration during recirculation period. It was observed that the COD concentration of OC-2 and OC-3 was higher than OC-1 and CLF at the beginning of recirculation; after that, the COD gradually decreased and slightly lower than OC-1 and CLF due to the acceleration of biodegradation by moisture infiltration. However, at the end of operation period, the concentration of COD of all lysimeters leveled off to around 900 mg/L and does not significantly differ between each lysimeter. Since the lysimeters were operated under rainy season for the first five months (July - November 2005) before recirculation mode was introduced, the decomposition of solid waste was already accelerated by available moisture content.

As the BOD/COD ratio were used to indicate the changes in the amount of biodegradable composition in the leachate and the BOD/COD ratio decrease as the biodegradation of organic waste occurs. A ratio of 0.4-0.8 implies high biodegradation (Ehirg, 1983; Tatsi and Zouboulis, 2002). The initial BOD/COD ratio of leachate from landfill lysimeters was in the range of 0.5-0.9, showing a good biodegradability of the organic contents and then decreased to 0.1 after nine months of operation.

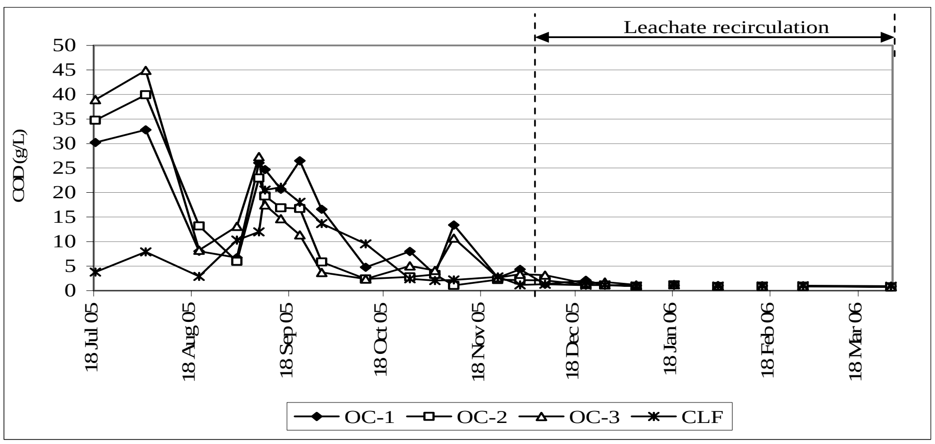

FIGURE 5: COD CONCENTRATION OF LEACHATE

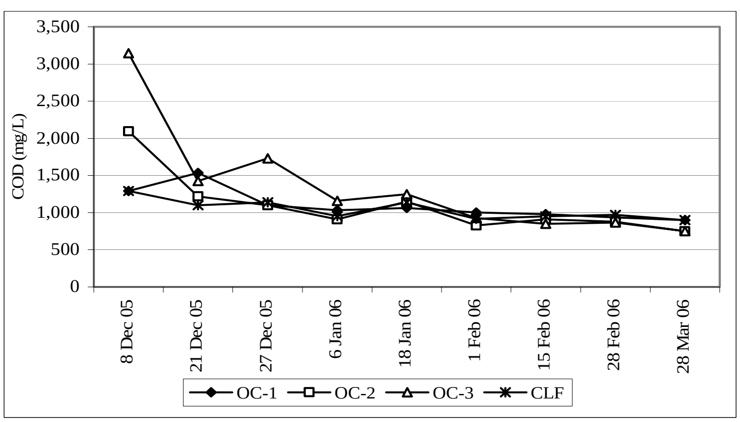

FIGURE 6: COD OF LEACHATE (DURING RECIRCULATION PERIOD)

Figure 7 illustrates the variation of TKN concentration in leachate from all lysimeters. The concentration of TKN was decreasing with time. It was observed that the leachate contains high concentration of NH_4-N which corresponds to about 75-98% of TKN, as the majority of TKN content is found to be in ammoniacal form (Tatsi and Zouboulis, 2002). The specific cumulative load of COD and TKN is calculated from the leachate generation and its composition is based from the starting weight (wet basis) of waste in the individual lysimeter (Tränkler et al., 2005). After nine months of operation, the results showed that the specific COD and TKN load discharged from open cell lysimeters (OC-1, OC-2, and OC-3) were higher than CLF.

The specific cumulative COD load presented a constant trend at the end of operation period (Figure 8). While, the specific cumulative load pattern of TKN showed a gradual increasing trend. Tränkler et al. (2005) indicated with the results of open cell simulation that the low compaction density with high organic content and without a cover may have permitted the system to obtain a partial aerobic condition. This could have improved the stability of the inorganic compounds followed by an instant leaching of solid waste by direct rainfall. As mentioned above, the top of lysimeters was partial-aerobic condition as a result of no top cover while at the bottom of lysimeters was anaerobic condition.

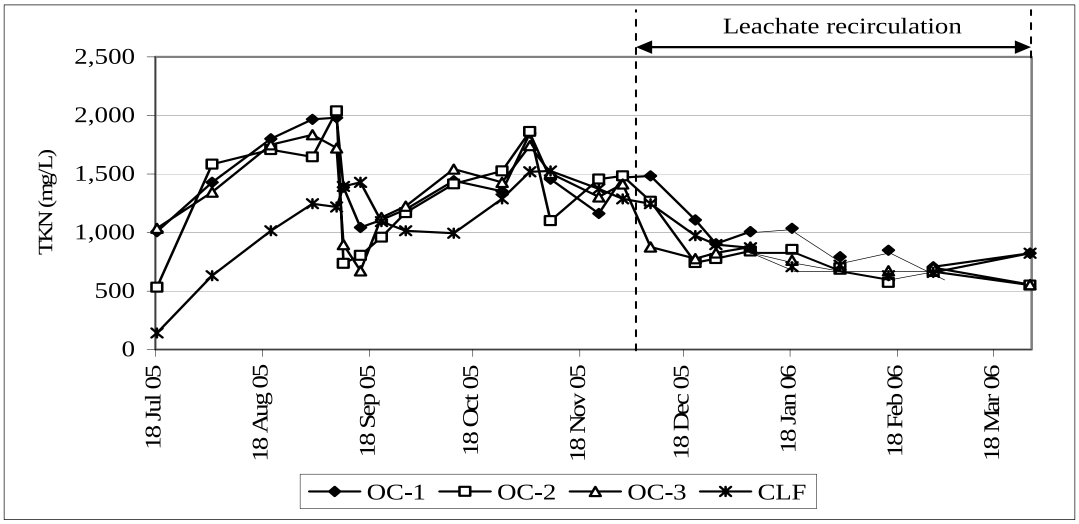

FIGURE 7: VARIATION OF TKN CONCENTRATION IN LEACHATE

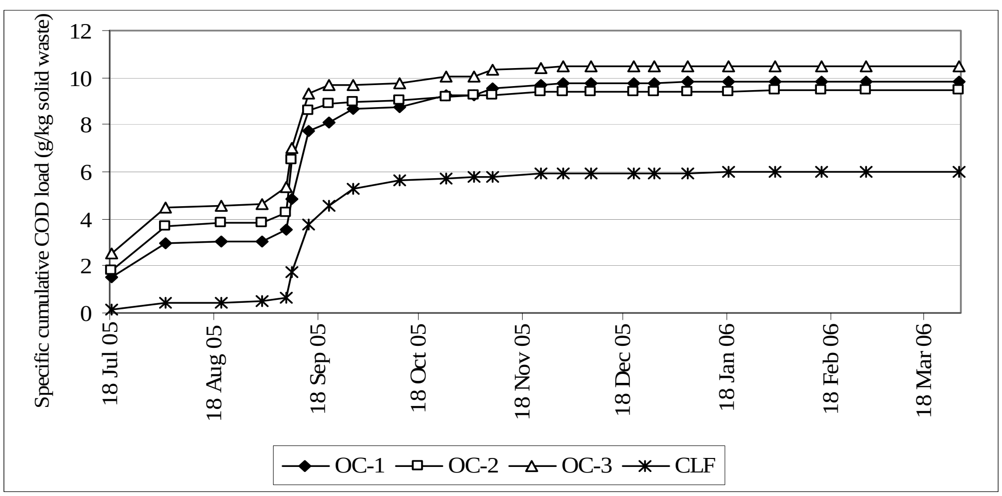

FIGURE 8: SPECIFIC CUMULATIVE COD LOAD IN LEACHATE

Settlement

Settlement extends the life of the landfill because the final site development is limited by elevation and not by volume or quantity. Thus, the settlement allows additional waste to be placed on completed areas (Reinhart and Townsend, 1998). The results of monitoring settlement variation from different operation of lysimeters are presented in Figure 9. Primary settlement occur rapidly, usually within the first month of landfill operation, followed by a substantial amount of secondary compression over and extended period of time (Ashford et al., 2000). All open cell lysimeters with low compaction had high settlement, while CLF with high compaction had the lowest settlement. After starting leachate recirculation into OC-2 and OC-3, the settlement rates increased higher than OC-1 and CLF. The settlement was enhanced by liquid flow and accelerated biodegradation by leachate recirculation. The variation of settlement was attributed to the biodegradation of solid waste.

After nine months of operation, the settlement of lysimeters OC-1, OC-2, OC-3 and CLF was 48, 53, 60 and 39 cm of initial height, respectively.

Water management for open cell lysimeters

Figure 10 illustrates the concept of water management for open cell landfill in tropical climate. In this study, leachate generation from OC-1 and CLF was collected and stored in closed tanks. While, leachate generation from OC-2 and OC-3 was managed by storing it into the separate open tanks (storage and evaporation tanks). These tanks also received rainfall during rainy season. At the same time, the evaporation of stored water enhanced by solar radiation. During dry period, stored leachate was introduced into OC-2 and OC-3. The evaporation of stored leachate in this period was very high. These actions resulted in the reduction of leachate remaining in storage tanks.

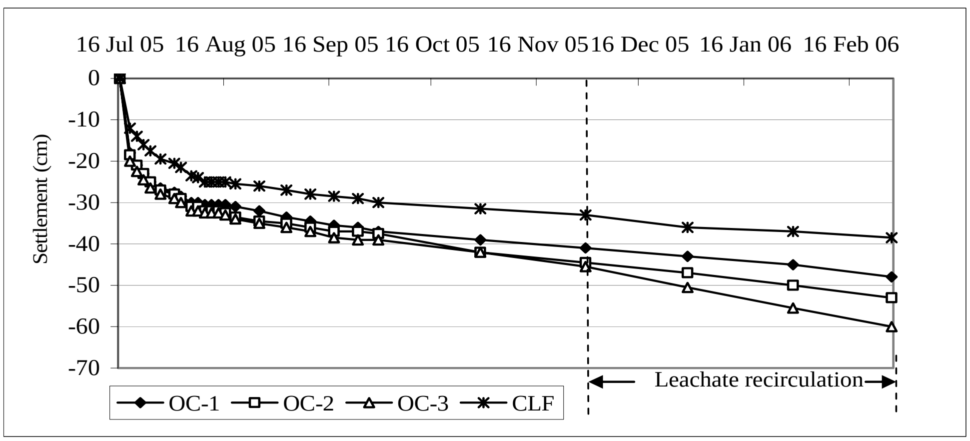

FIGURE 9: SETTLEMENT OF LYSIMETERS

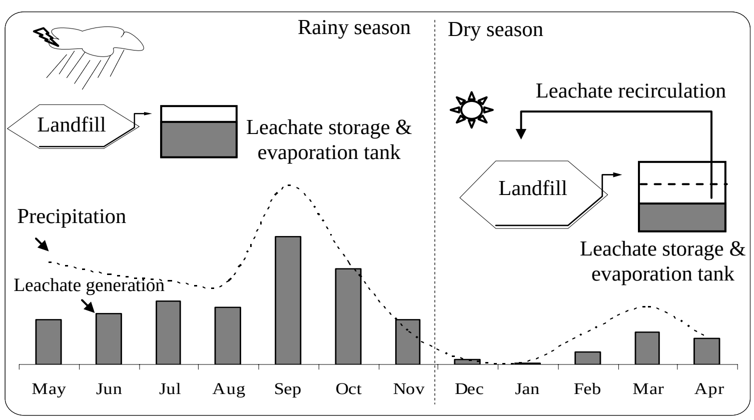

FIGURE 10: CONCEPT OF WATER MANAGEMENT FOR OPEN CELL LANDFILL IN TROPICAL CLIMATE

Figure 11 presents the variation of leachate remaining in each tank through the operation period. The results of water management of OC-2 and OC-3 showed high leachate remaining in storage tanks during rainy period. The peak leachate remaining of OC-2 and OC-3 was 1,700 L and 1,785 L, respectively. It was noted that from July to August 2005, leachate was stored in the small open tanks because of small amount of leachate generation and less rainfall. The high reduction of the remaining leachate volume was observed during dry season as a result of leachate recirculation and evaporation. The remaining leachate from these two lysimeters at the end of operation period was around 562 L and 617 L, respectively. While the remaining leachate from OC-1 and CLF was 1,194 L and 1,029 L, respectively. The concentration of leachate pollutant remaining in the storage and evaporation tank varied depending on the dilution by rainfall and evaporation. The small amount of leachate with high concentration of pollutant was easy to handle. Therefore, water management reduced the amount of leachate and accumulates pollutant concentration for treatment.

At the same time, leachate recirculation accelerates waste stabilization and increased the settlement of lysimeters. Higher evaporation rate was significant for water management to achieve the small amount of leachate remaining. However, there should be enough leachate remaining for recirculation purpose through the cycle of operation period. Determining the disposal of accumulated settled sludge in the remaining leachate was also important because sludge was inappropriate for recirculation system.

In practice, water management of open cell landfill should be considered as a whole system. The design and operation of open cell landfill should provide enough leachate for recirculation and at the same time minimize the leachate remaining. Figure 12 shows the water management components. From the equation, the understanding of water management for open cell landfill can be conducted by considering the details of these components. The minimum water remaining was also investigated to balance the system.

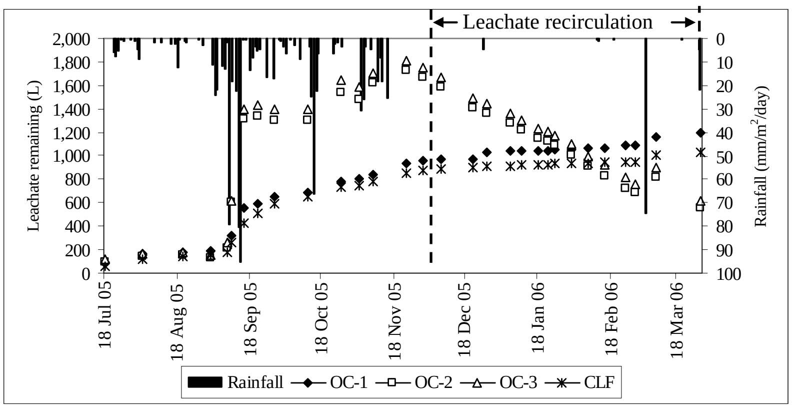

FIGURE 11: RESULTS OF WATER MANAGEMENT OF LYSIMETERS

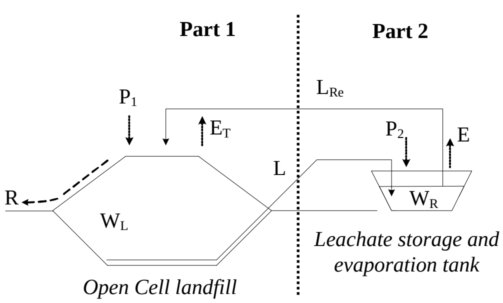

FIGURE 12: WATER MANAGEMENT COMPONENTS OF OPEN CELL LANDFILL

Water management equation:

$$\mathbf{W_R = (P_1 + P_2) - (E_T + E) - R - W_L}$$

W_L	= quantity of moisture storage in landfill (L)
W_R	= quantity of water remaining in storage tank (L)
P_1	= quantity of precipitation come in landfill (L)
P_2	= quantity of precipitation come in storage tank (L)
R	= quantity of runoff from landfill (L)
E_T	= quantity of evapotranspiration from landfill (L)
E	= quantity of evaporation from storage tank (L)
L	= quantity of leachate generation from landfill (L)
L_{Re}	= quantity of leachate recirculation (L)

CONCLUSIONS

The comprehensive study of open cell lysimeters operation by combining with leachate recirculation revealed that OC-2 and OC-3 showed lower concentration in COD and TKN than in OC-1 and CLF. Leachate recirculation leads to waste volume reduction. The easily biodegradable waste used in OC-3 was related to the highest cumulative leachate generation, specific cumulative COD load and settlement rate. However, monitoring the influence of leachate recirculation on open cell lysimeters should be continued for long period including evaluation of waste stability. Water management of open cell lysimeters by storage, evaporation, and recycle leachate showed the reduction of remaining amount of leachate. After nine months of operation, the volume of leachate remaining for OC-2 and OC-3 is 47% lower than OC-1 and CLF. The advantages of water management for open cell lysimeters which included leachate recirculation accelerates waste stabilization and reduced leachate remaining for treatment. Experiment on water management by investigating the minimum water remaining for leachate recirculation through the operation period should be determined by considering the water management components. Enhancing the evaporation by using solar radiation should be considered to minimize the water remaining for treatment.

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Open Cell Approach towards Sustainable Landfill Operation in Tropical Asia

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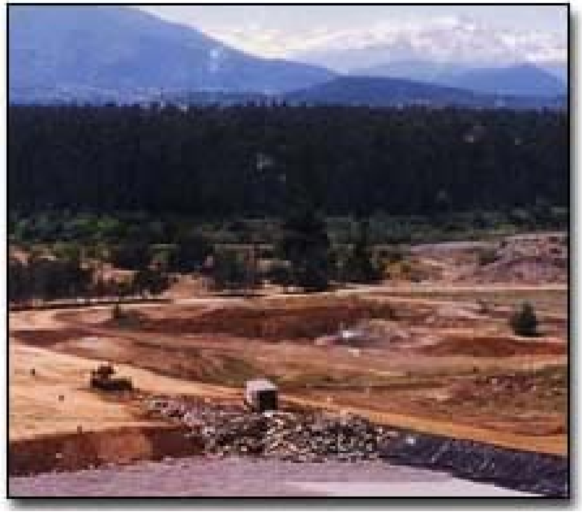
Open Cell Operation Combining with Water (Leachate) Management

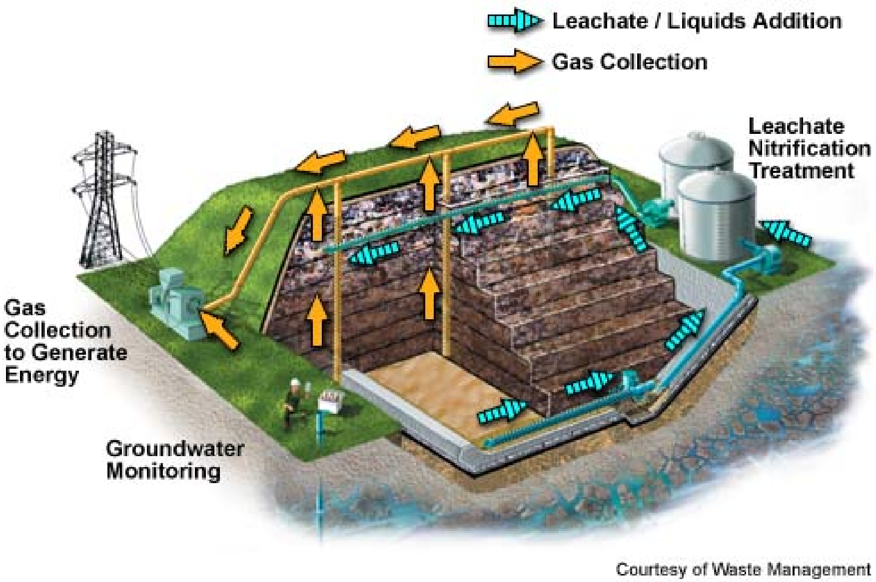


- ✓ Traditional disposal practices in Asia
- ✓ Landfill technology
  - Sanitary Landfill
  - Bioreactor Landfill
- ✓ Tropical seasonal variation influences leachate generation in landfill

Sanitary Landfill

Bioreactor Landfill





- Storage / containment system
- Minimize infiltration of water

- Slow degradation rate
- Long term aftercare

- Process-based approach
- Leachate recirculation

- Accelerating the waste stabilization in short time
- Energy recovery

Objectives of Study

To determine the influence of leachate recirculation on Open Cell landfill lysimeters

- To determine possible option for water (leachate) management of Open Cell landfill lysimeters by experiment
- To recommend an appropriate Open Cell landfill and leachate management option for sustainable landfill in correlation with the Asian tropical climate

Methodology

Task I

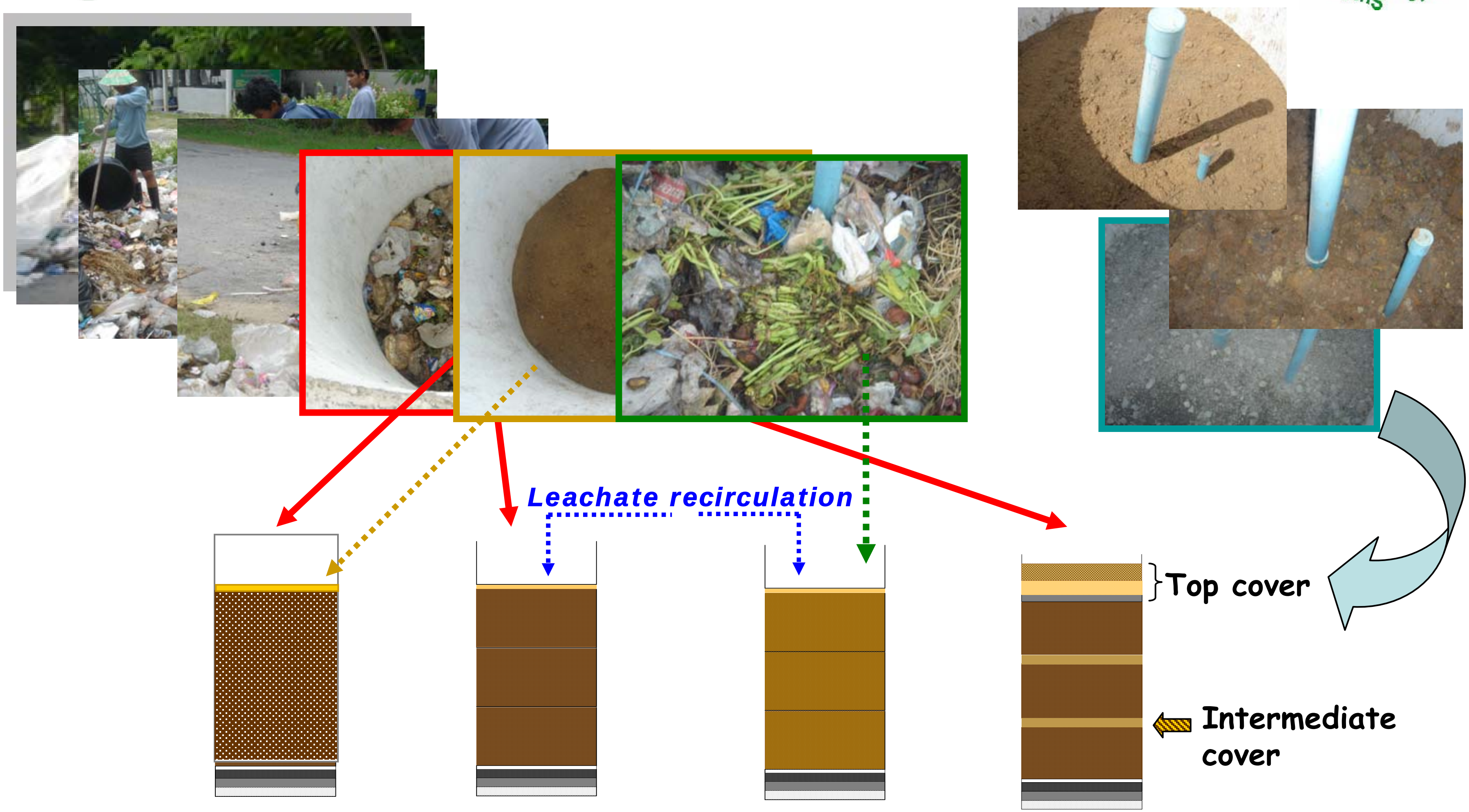
Monitoring
four landfill lysimeters

Task II

Determining
water management

Landfill Lysimeters

Task I: Lysimeter Preparation



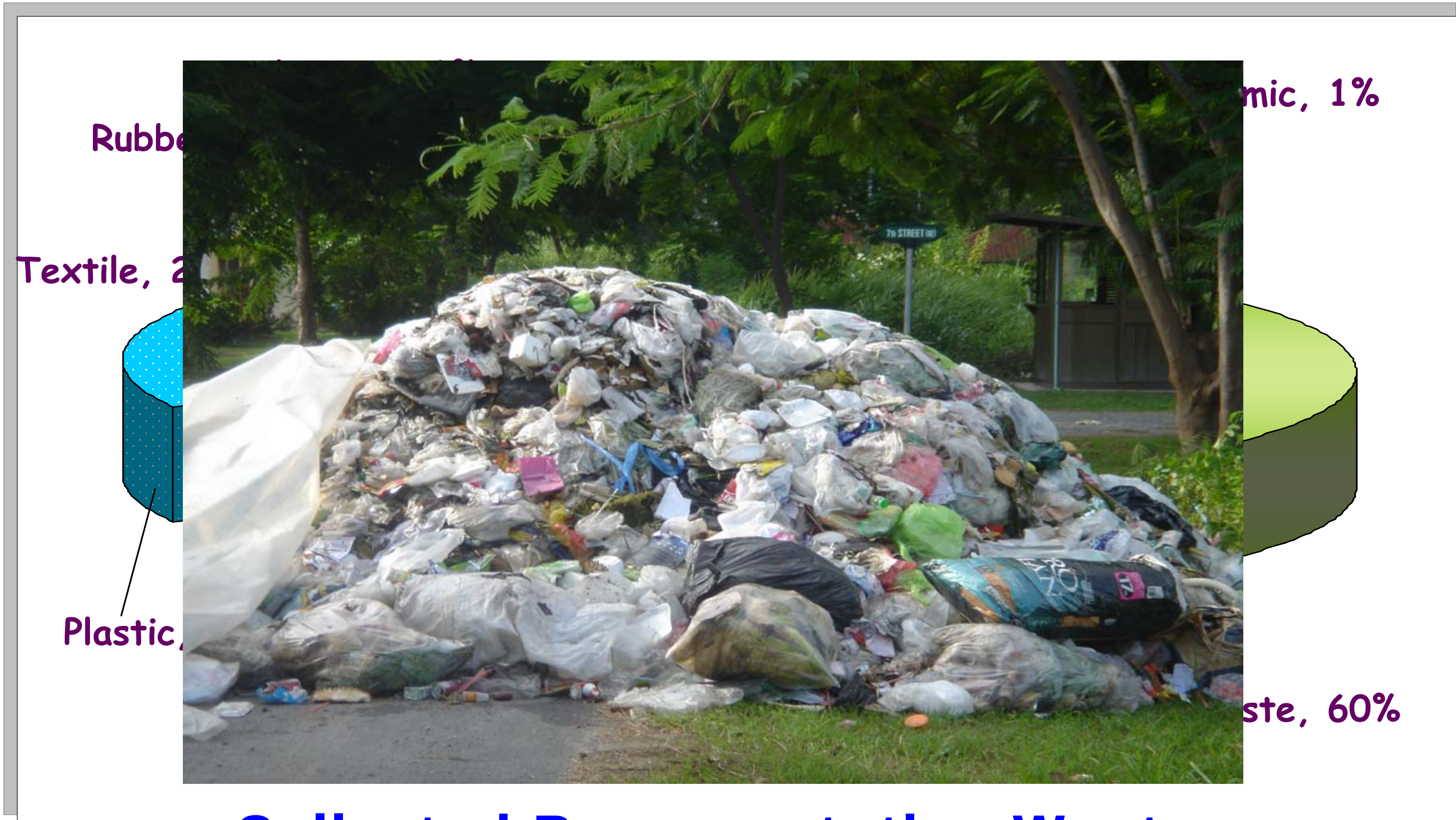
Open Cell 1 (OC 1)

Open Cell 2 (OC 2)

Open Cell 3 (OC 3)

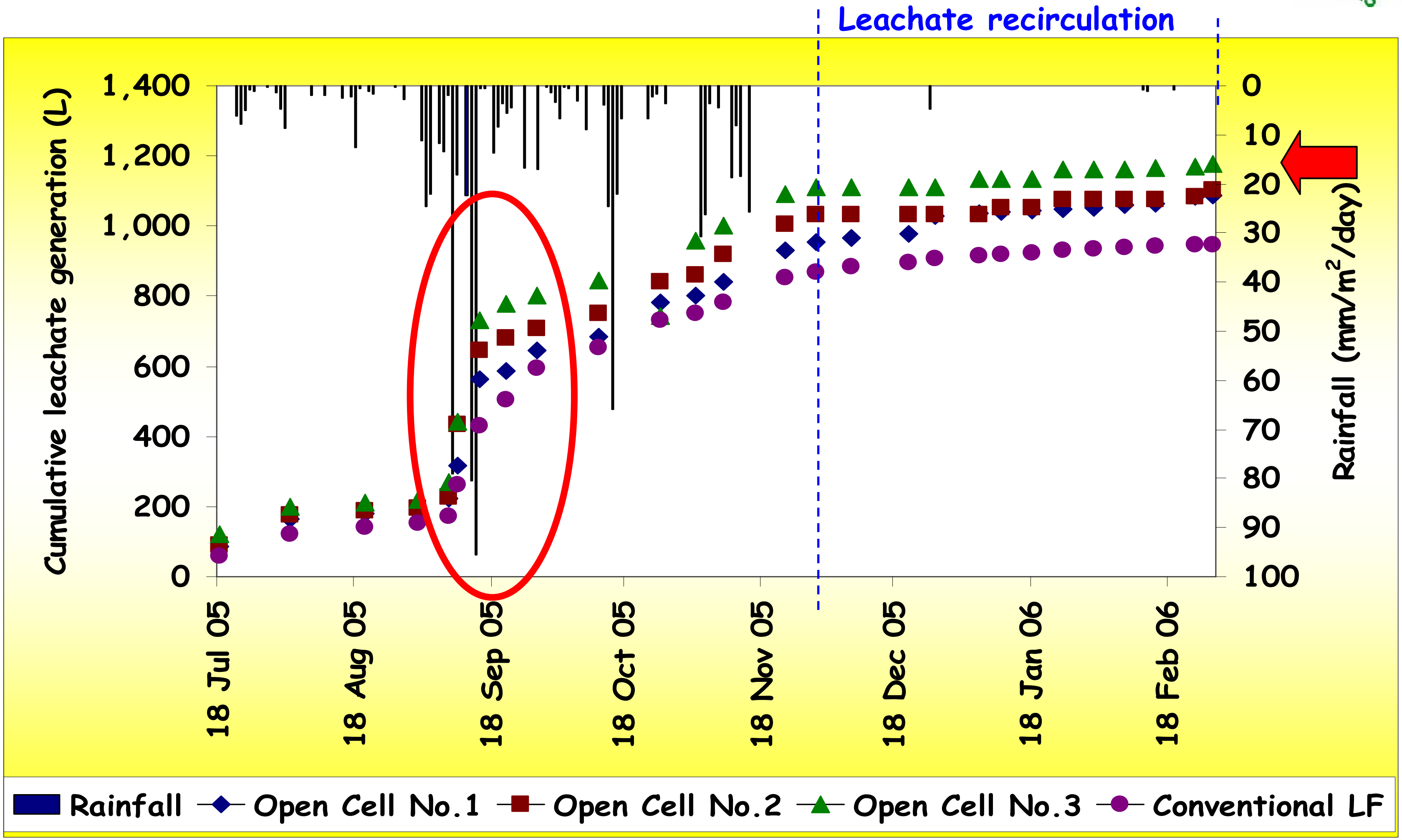
Conventional Landfill (CLF)

Task I: MSW Characterization



Collected Representative Waste

Task I: Leachate Generation

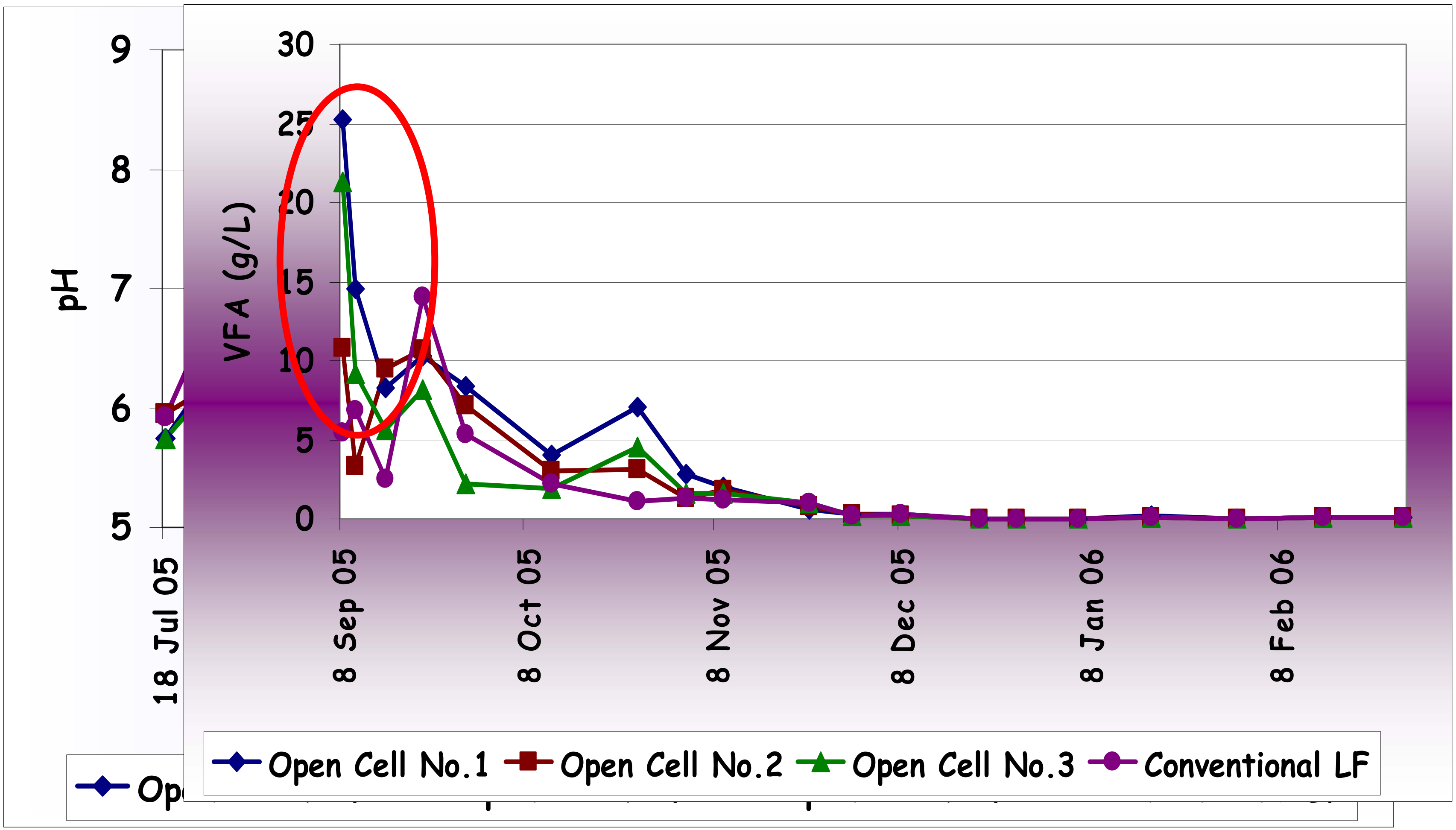


Task I: Leachate Characteristics

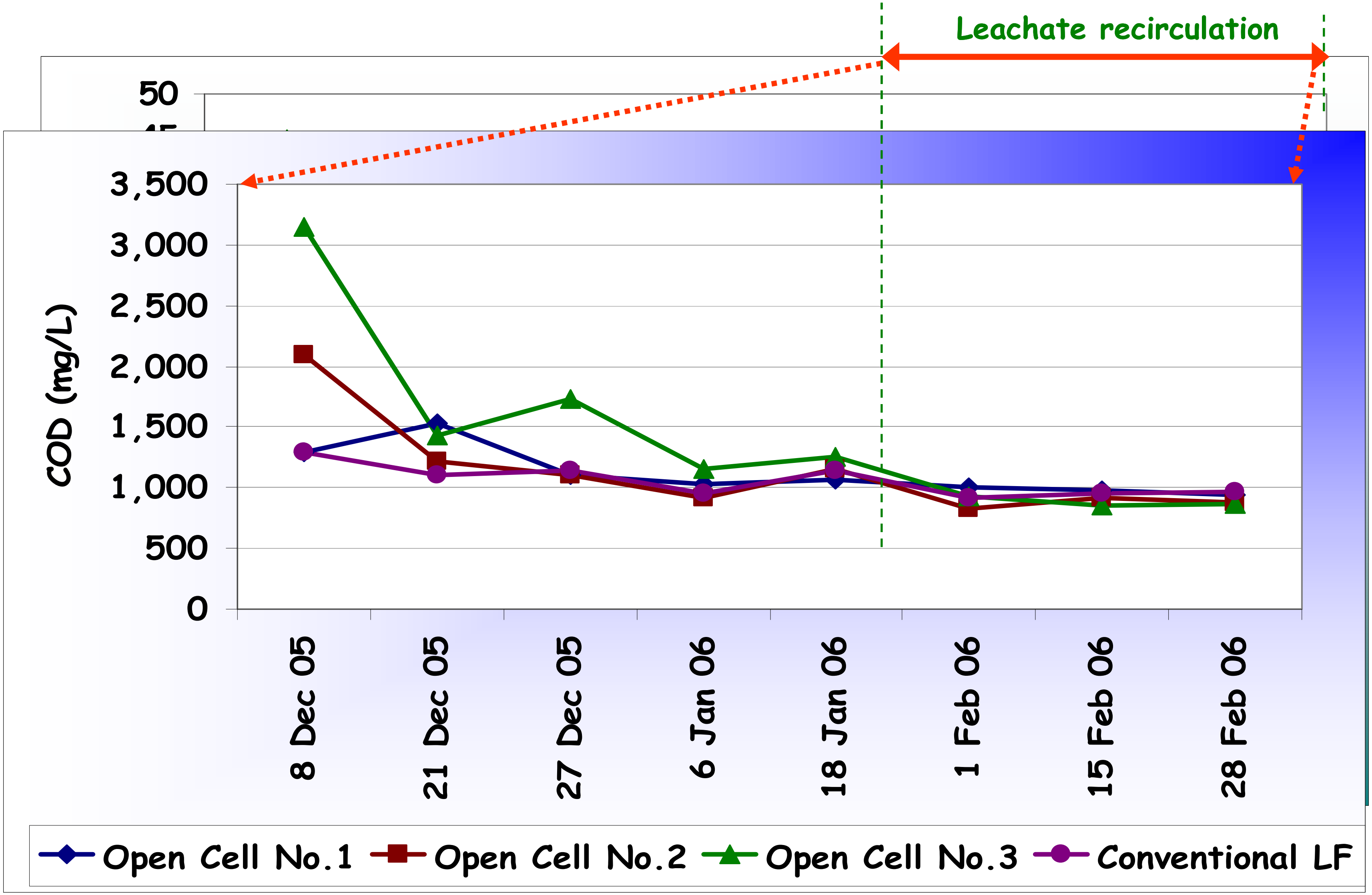
Parameters analyzed

- pH, Conductivity, Alkalinity, TS, VS, TDS and TSS
- Organic contents: COD, BOD and VFA
- Inorganic contents: TKN, NH_4-N and Organic-N
- Carbon and Nitrogen load
- Heavy metal: Mn, Cr, Cd, Pb, Ni, Zn and Cu

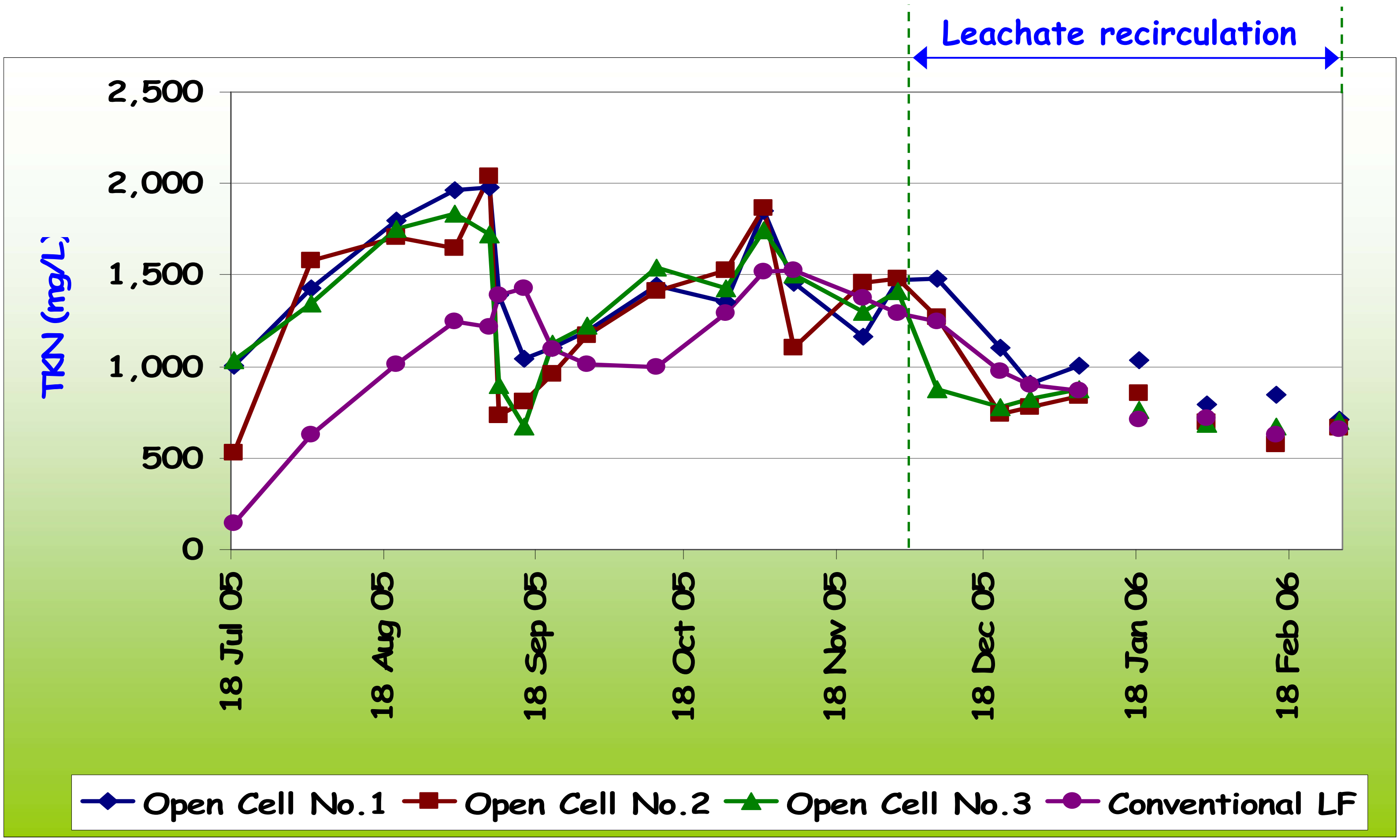
Task I: Leachate Characteristics (pH and VFA)



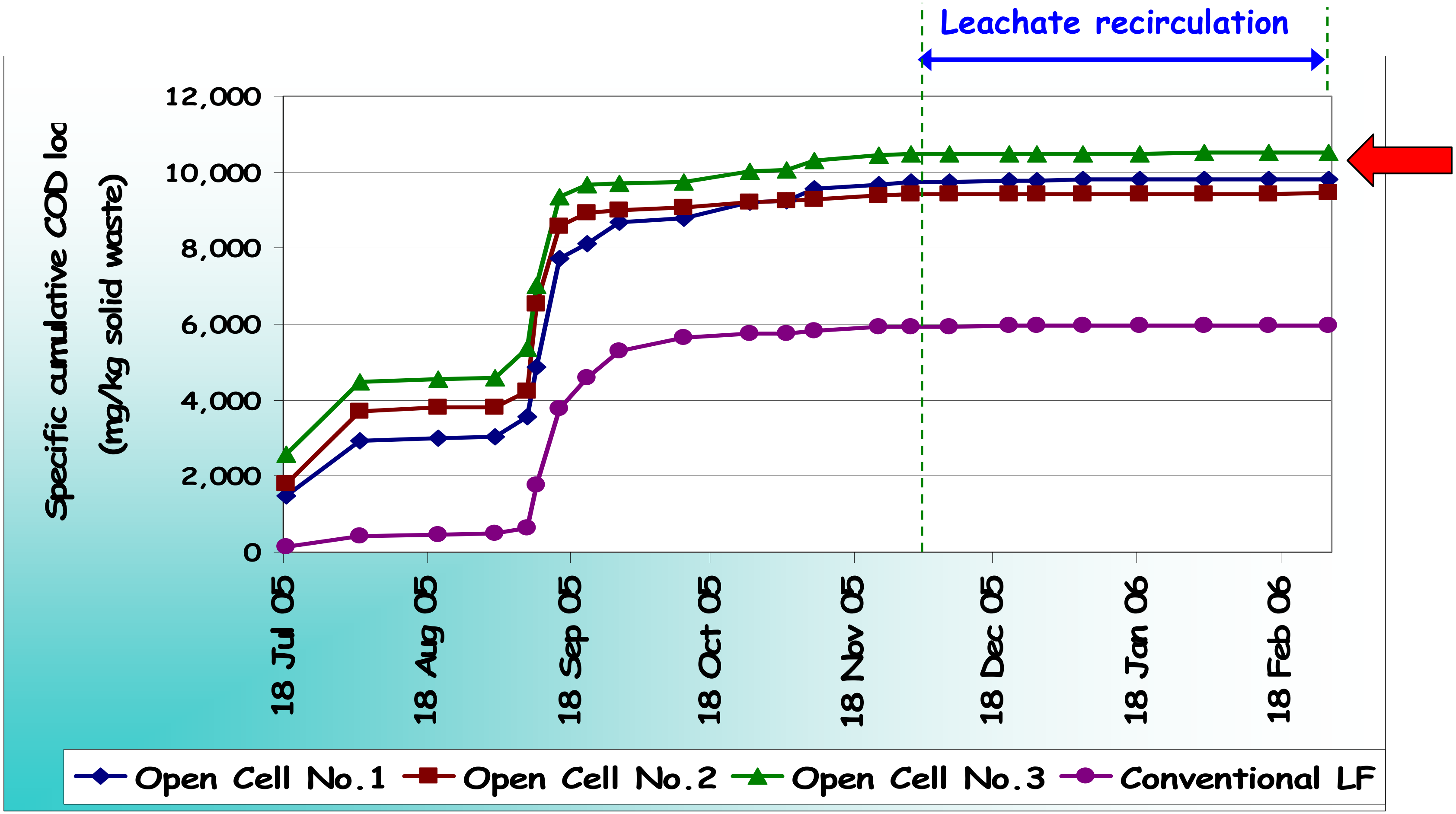
Task I: Leachate Characteristics (COD)



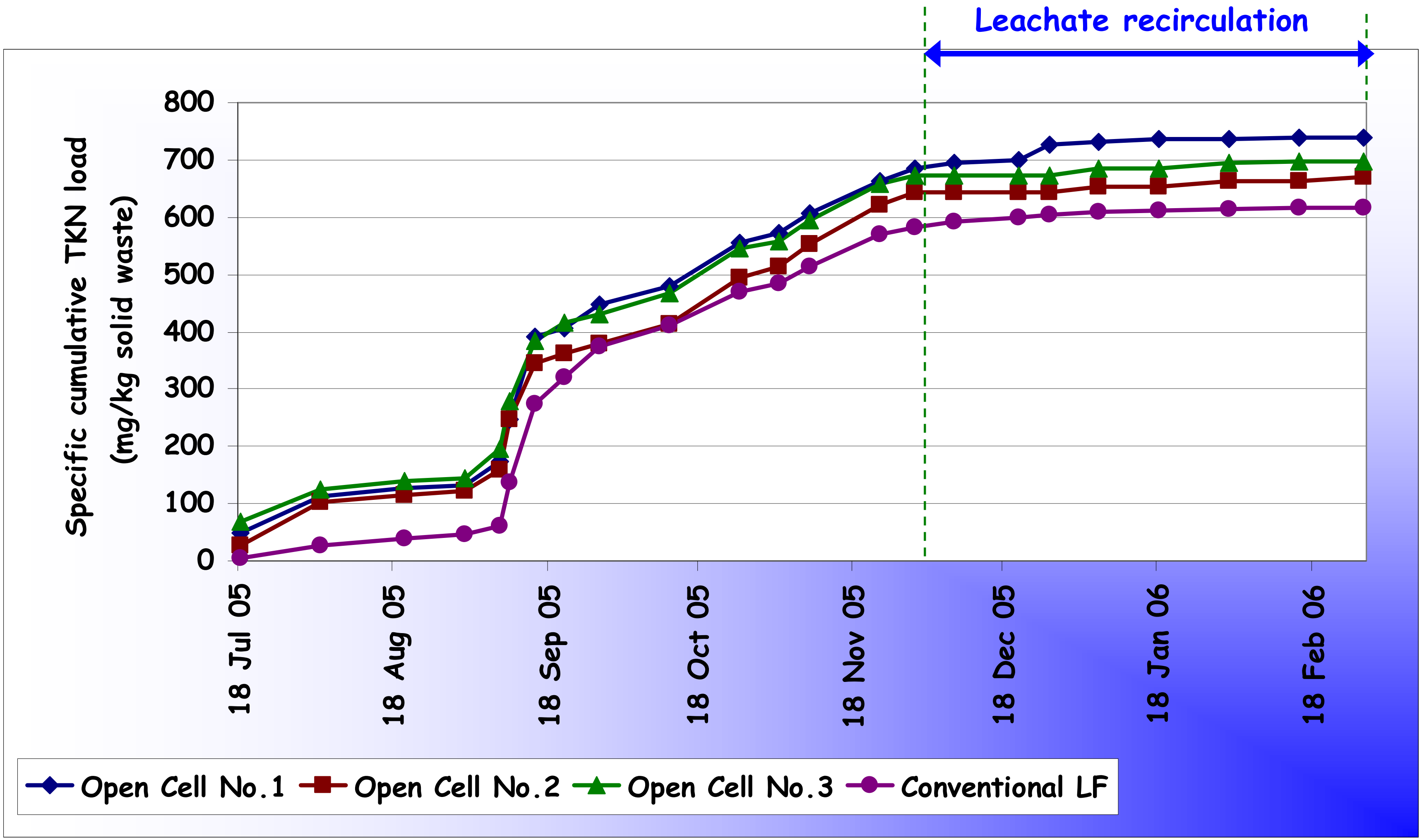
Task I: Leachate Characteristics (TKN)



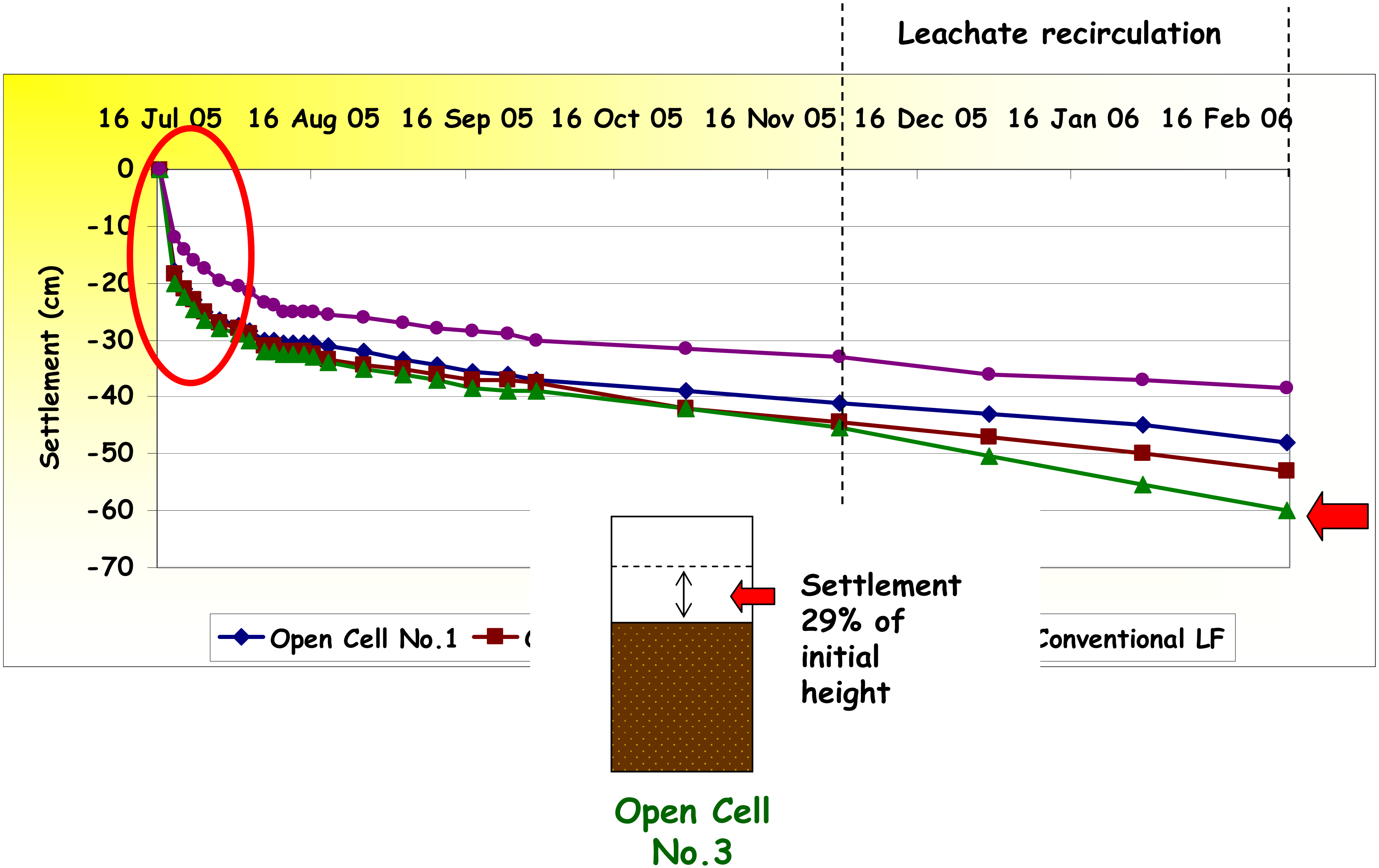
Task I: Leachate Characteristics (COD load)



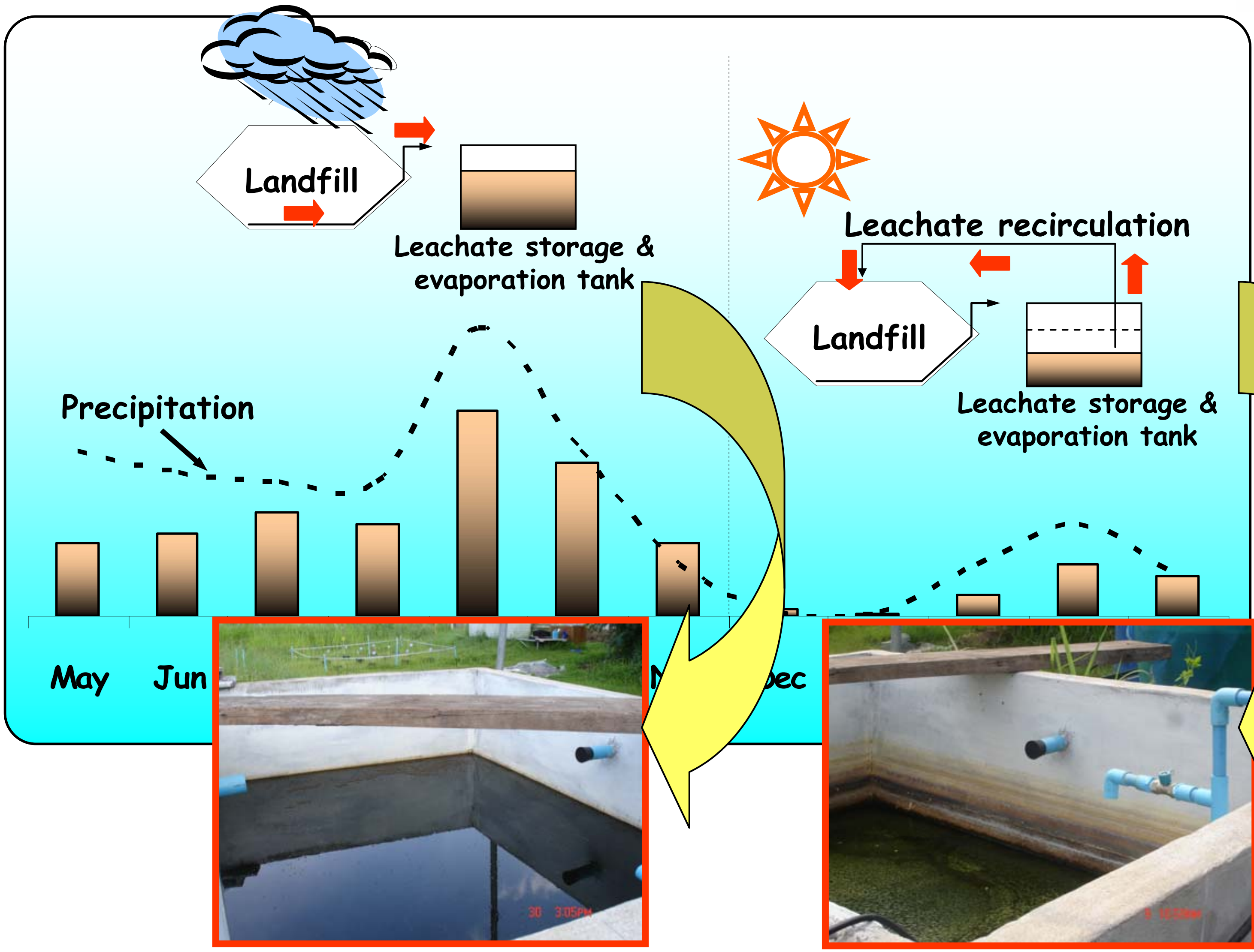
Task I: Leachate Characteristics (TKN load)



Task I: Settlement

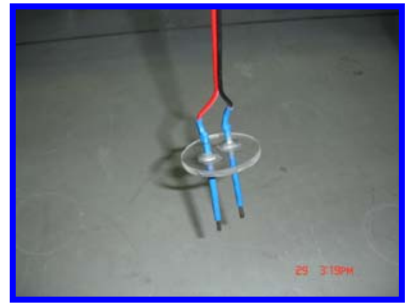


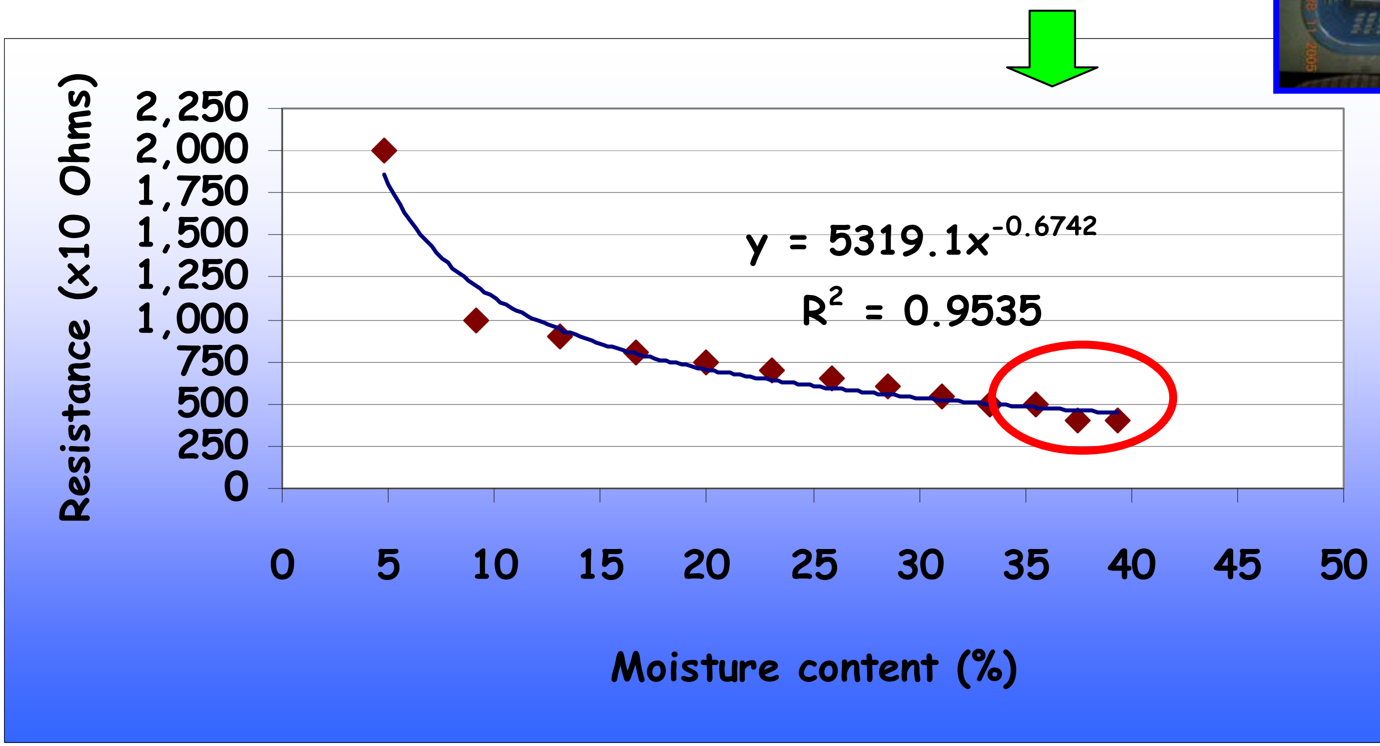
Task II: Water management



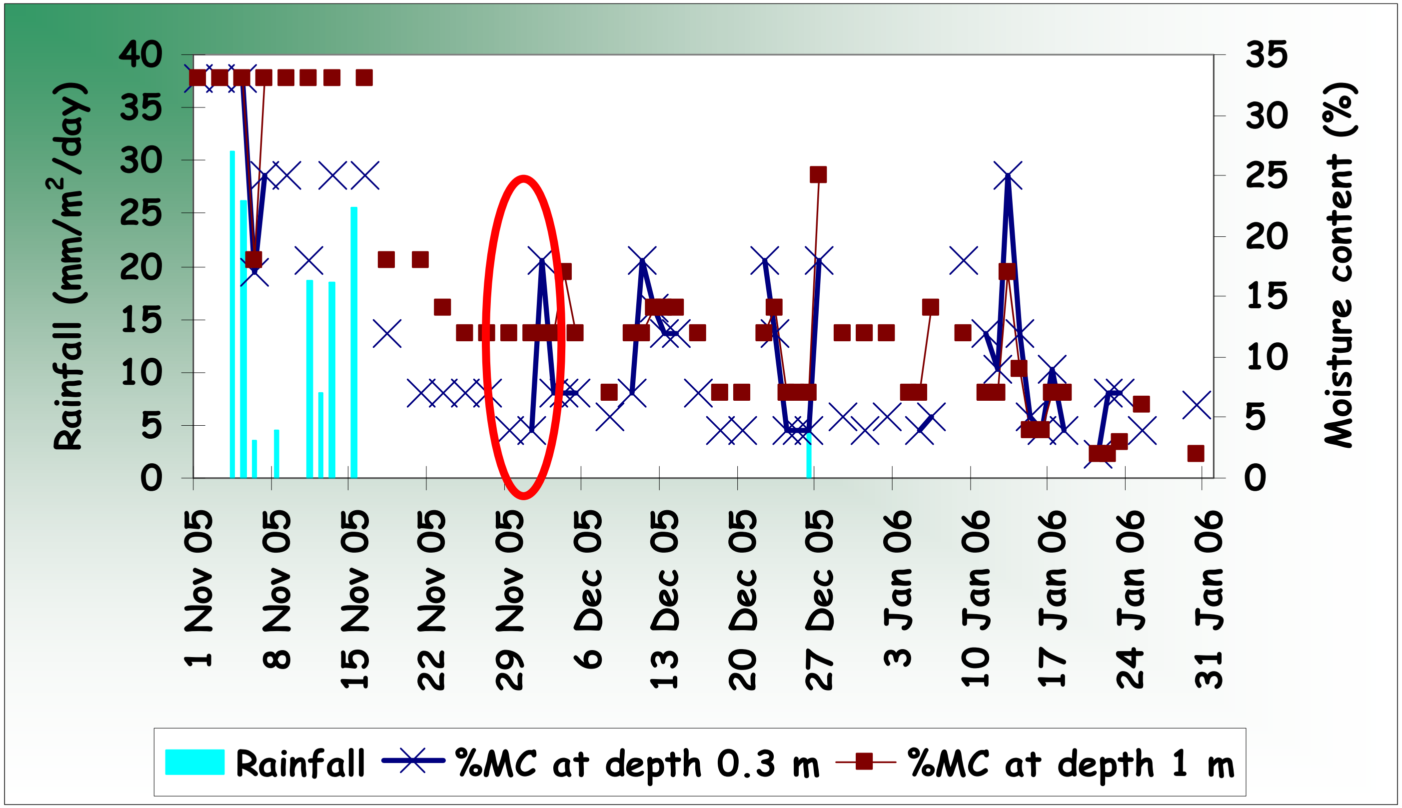
Task II: Leachate recirculation

Electrical resistance sensor for moisture content

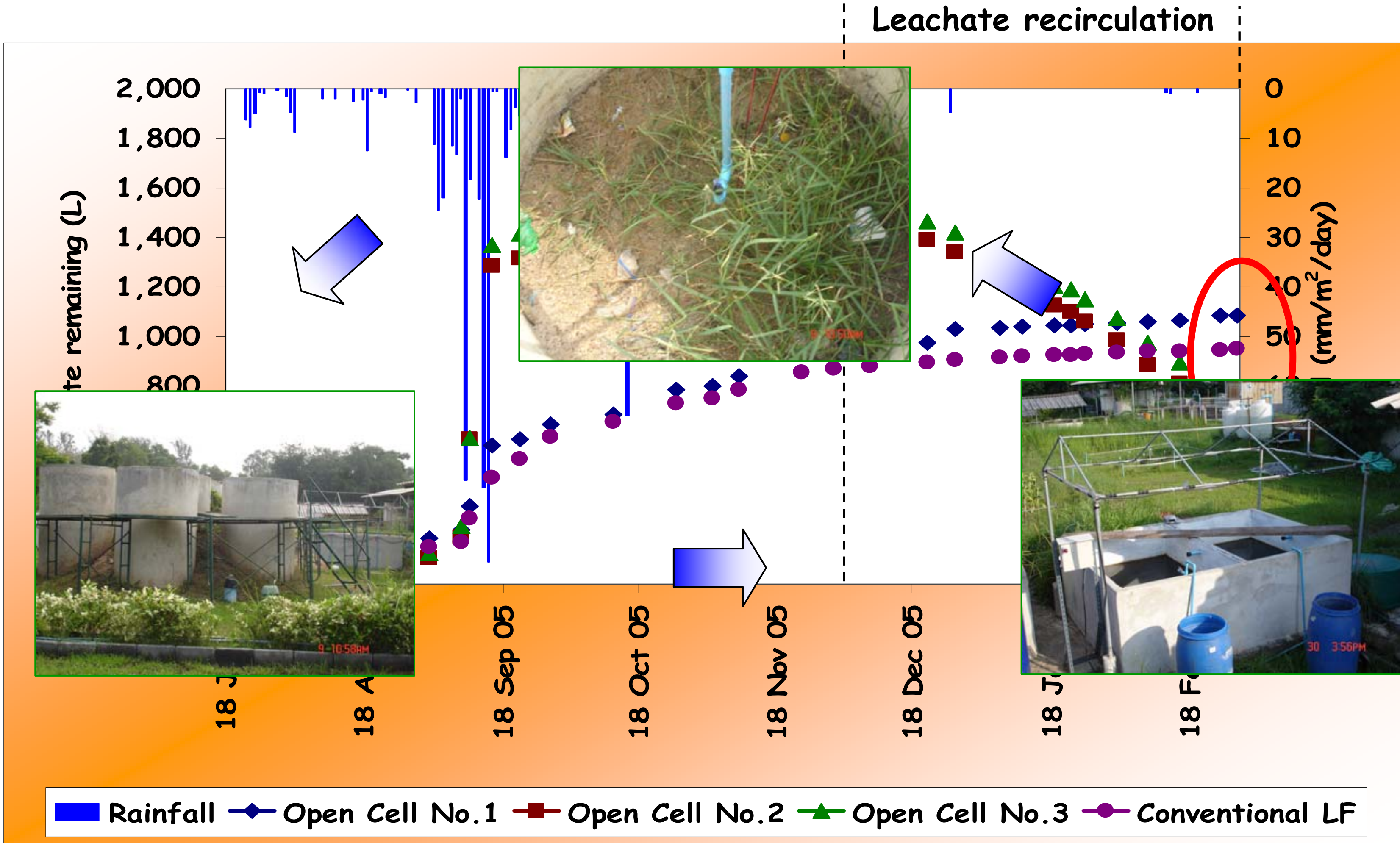




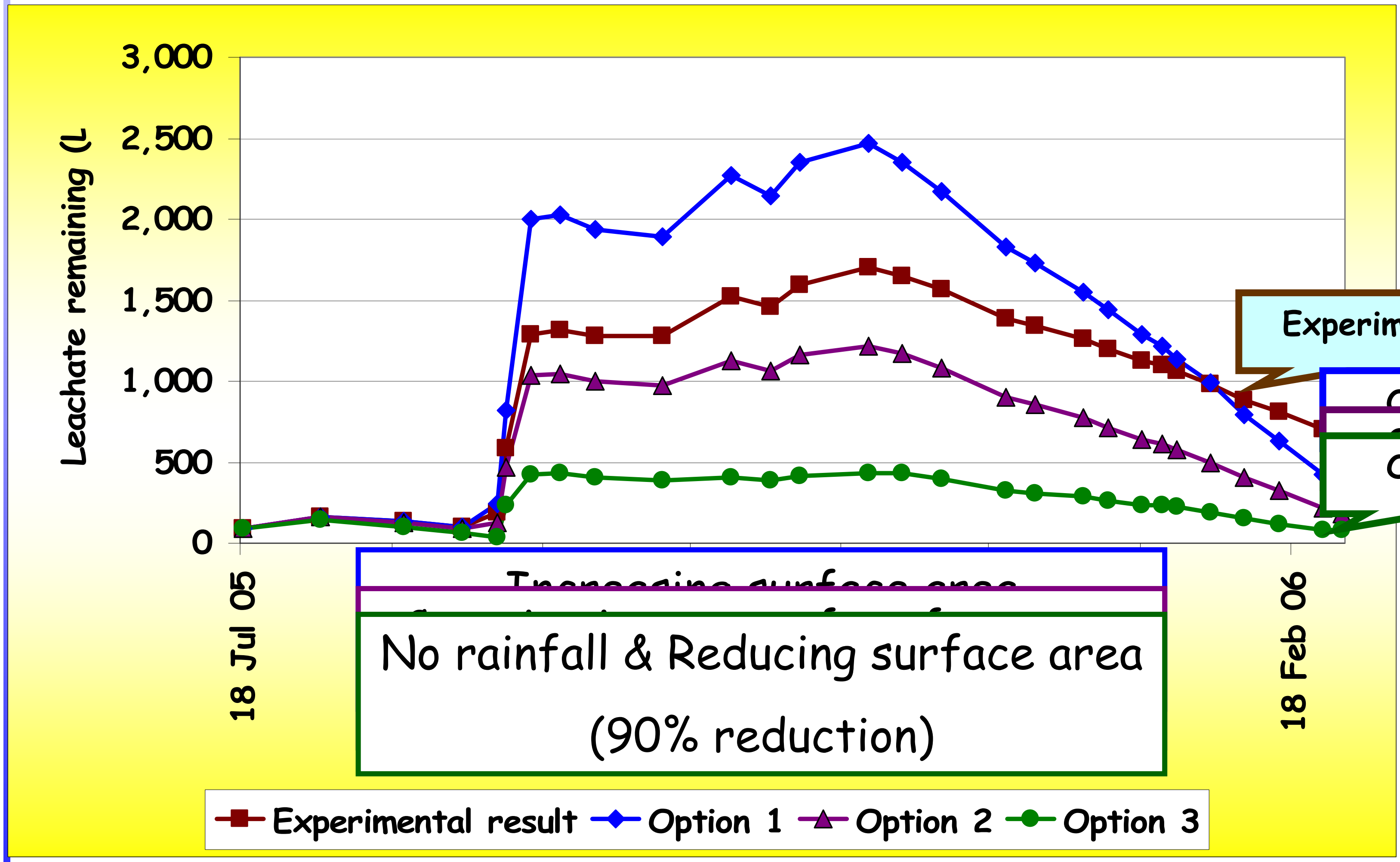
Task II: Leachate recirculation



Water Management for Open Cell



Task II: Options of Improving Water Management for Open Cell Landfill Lysimeters



Conclusions

- **Open Cell landfills:** lower concentration of pollutant,
  higher specific cumulative COD and TKN load
  and higher settlement than **Conventional Landfill**

- **Open Cell No.3:** highest cumulative leachate generation, specific cumulative COD load and settlement rate

- **Leachate recirculation:** low flow rate, intermittent application, uniform distribution ⇔ Moisture content sensor

- **Water management:** for Open Cell No.2 and 3 lead to 30% reduction in volume of leachate for treatment compared with Open Cell No.1 and Conventional landfill ⇔ Evaporation