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Chapter 7

Post-Treatment and Microbial Risk Assessment of Compost for Food Production

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Additional information is available at the end of the chapter

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Abstract

The compost withdrawn from a composting toilet still contains pathogens and therefore requires a post-treatment unit to treat the compost prior to reuse on an agricultural land. A quantitative microbial risk assessment with Monte Carlo technique was conducted to evaluate the risk of infectious disease and length of time required for the post-treatment. The incidental ingestion of compost (0.5–0.8 g) in a scenario of worst case was evaluated. High temperature was efficient in reducing the risk of pathogens; however, the temperature distribution in the unit (steel box) was not sufficient to reduce pathogens. Therefore, to efficiently reduce pathogens during the post-treatment and also reduce the time of treatment, the steel box needs an insulator to maintain the temperature. The guidelines for the design of the post-treatment facility are: for *Ascaris*, the steel box and the lower temperature −5, −10 and −15°C, post-treatment requires approximately 295 h to achieve the safe level of 10^{-4} pppy. For norovirus, post-treatment requires approximately 845 h for the scenarios to achieve a safe level. *Salmonella* requires 969.5 h, for all scenarios to reach a safe level.

Keywords: post-treatment, risk assessment, compost, pathogens, temperature

1. Introduction

Compost of human faeces used as fertiliser can be harmless and useful because it becomes part of nutrient recovery. A pilot model of a composting toilet was installed in a rural region of Burkina Faso to perform a source recycling system which makes compost from human faeces. Initial experiments were performed on some samples taken from the composting toilet. Results showed that pathogens such as bacteria and parasites still remained in the

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compost after withdrawal from the rural model of composting toilet after 3 months of operation. Therefore, post-treatment of the collected compost is required to minimise the health risk when recycling the faeces as fertiliser on farmland. For the inactivation of pathogens, several methods of treatments are proposed, including heating, drying, chemical treatments, treatment by worms, long storage times, etc. In low income countries some people cannot pay materials for post-treatment, however, they have abundant solar energy. Therefore; this study proposes a solar disinfection unit to inactivate the pathogens. The operation condition to inactivate pathogens should be designed based on the risk assessment by setting a safe level of pathogens concentration in the compost after post-treatment.

Norovirus, *Ascaris* eggs and *Salmonella* were selected as reference pathogens in this study. Noroviruses are a major cause of human gastroenteritis, and they are frequently associated with food, water contamination [1] and accidental ingestion. *Ascaris* infections are very common in developing countries. One fertile egg can cause infection of Ascariasis to humans. The carrier state of *Salmonella typhi* is defined as persistent shedding in faeces for greater than 12 months [2].

These enteric infections can be transmitted through the compost from faeces to the human body with pathogenic species. Quantitative microbial risk assessment (QMRA) has been widely used to establish the health risks associated with wastewater reuse in both developed and developing regions under different scenarios. The QMRA-Monte Carlo techniques (QMRA-MC) based on the work of Haas et al. [3] was used to estimate risk in this study.

The objectives of this study are to perform risk assessment for the design of the post-treatment unit by using the QMRA-MC and to determine the treatment time to reach the safe level of pathogens in the compost.

2. Material and methods

2.1. Post-treatment unit

People would collect the compost from the rural model of composting toilet with urine diversion (**Figure 1**) in the pilot families and used it in their gardens as fertiliser. Application of the post-treatment would be achieved by spreading the compost evenly in the steel box as shown in **Figure 2**, and leaving it under the sunshine. The steel box was fabricated with a length of 60 cm, a width of 40 cm, and a depth of 10 cm. The total volume of the box is 24 L. The steel box has steel septa which facilitate deep penetration of heat to compost. The steel box is painted black in colour to aid in the absorption of heat. The steel box does not have a solar concentrator [4, 5]. The temperature distribution of the compost in the box was measured at 3 positions which were 1, 5, and 10 cm from the surface.

2.1.1. Scenarios for reuse of compost

During the utilisation of the compost, people may accidentally ingest compost with the pathogens orally. The people exposed to the pathogens would have diseases with a probability estimated by risk assessment. The temperature distribution was considered at 3 positions as top,

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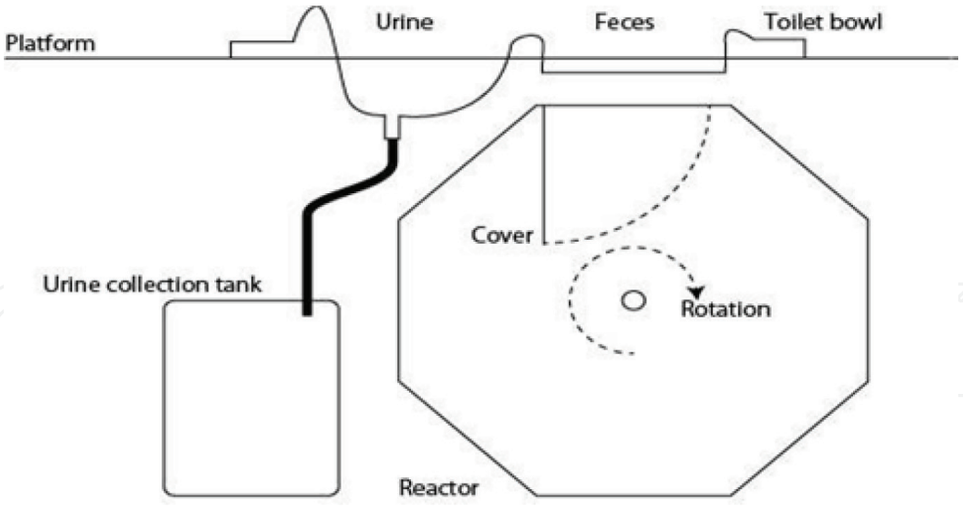


Figure 1. Arrangement of the composting toilet.

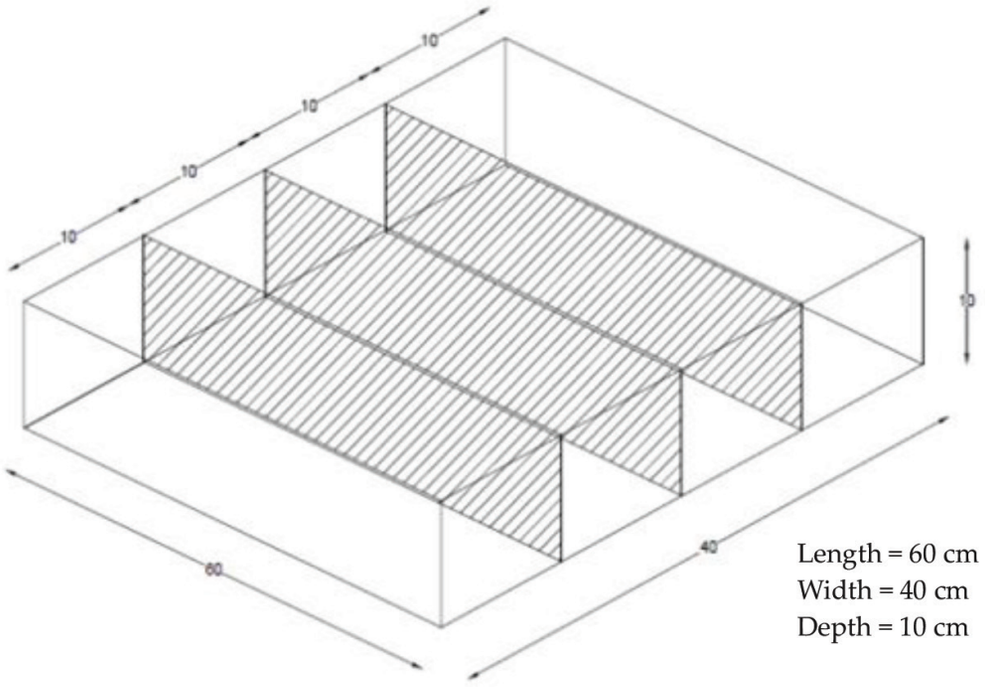


Figure 2. A proposed compost solar sanitisation installation that could reduce the heat loss [4].

middle and bottom at 1, 5 and 10 cm depth from the top surface, respectively. A basic scenario was set at actual temperature in the steel box (S1) as a post-treatment for the assessment. For investigating the effect of temperature, 3 temperature levels, such as −5°C lower temperature as S2, −10°C lower temperature as S3 and −15°C lower temperature as S4 derived from the temperature measured in the steel box, were considered in this simulation, because the temperature varied by weather conditions. For the calculation of concentration in the compost, the inactivation rates coefficient from the previous measurement were used [6]. The details of the ingestion model are as follows:

- To consider the worst case, 50,000 eggs/g in wet faeces is excreted from a heavily infested person [7]. The value of the initial concentration of *Ascaris* eggs was 336 eggs/g-dry compost. This number was estimated by multiplying the number of eggs excreted per gram (50,000 eggs/g) by the 100 g of compost dividing by the bulk density of the compost.
- Highly infested person of viral infection excretes a maximum of 10^{11} viral copies/g in faeces from highly infected person [1, 8, 9] was used for the risk assessment taking account of the highest risk. Assuming this concentration, the initial concentration was estimated at 6.72×10^8 viral copies/g-dry compost. This number was estimated by multiplying the number of norovirus excreted per gram (10^{11} viral copies/g) by the 100 g of the compost and dividing by bulk density of the compost.
- Concentration of *Salmonella* spp. in faeces is 10^4–10^{10} per gram of faeces [3]. Assuming this concentration, the initial concentration was estimated at 6.72×10^7 CFU/g-dry compost. This number was estimated by multiplying the number of *Salmonella* excreted per gram (10^{10} CFU/g) by the 100 g of the compost and dividing by bulk density of the compost.
- Ingestion rate of compost is 150–800 mg/event. This is used in the risk assessment of dioxin in soil ingestion rate [10].
- Post-treatment would be done every 4 months.
- The concentration of pathogens in the compost after the post treatment was estimated using the first-order kinetic model from the earlier studies on *Ascaris* eggs and indicator MS2 bacteriophage inactivation and *E. coli*. The data from these experiments were used to re-estimate the inactivation rate co-efficient [6].
- The moisture content of all treatments was 50%.

2.1.2. Hazard identification

Farmers performing post-treatment would be exposed to pathogens in the compost. There are several groups of pathogens, but the pathogens of considerable interest in the study area are *Ascaris* eggs, viral infections (norovirus) and *Salmonella* because *Ascaris* and norovirus are also known to be the most resistant to treatment processes [11, 12]. Burkina Faso recorded 32.8% of bacteraemia among febrile children admitted to hospital (non-typhoid *Salmonella*) between 2012 and 2013 [2] and it is also reported that the carrier state of *Salmonella* typhi is defined as persistent shedding in faeces for greater than 12 months [2]. Accidental ingestion of a small dose consequently implies a high risk of infection compared to many other pathogens [10].

2.1.3. Dose-response assessment

The QMRA-MC was used to estimate risks of *Ascaris* and norovirus and *Salmonella* infections. The study by Navarro et al. [13] found that *Ascaris* infection data best fitted the β-Poisson dose-response equation [13]:

$$P_I(d) = 1 - \left[1 + \left(d/N_{50}\right)\left(2^{1/\alpha} - 1\right)\right]^{-\alpha} \quad (1)$$

where P_I (d) is the probability of infection in an individual (infection/event), d is the ingested number of *Ascaris* eggs on one occasion (eggs/event), N_{50} is the mean infective dose number of *Ascaris* eggs (eggs), I means considerable spice for calculation of probability (−) and α is an infectivity constant of *Ascaris* (−). They found the values of N_{50} and α to be 859 and 0.104, respectively. Since they were working with epidemiological data on *Ascaris* prevalence rather than conducting human *Ascaris* dose-challenge studies, the value found for N_{50} is not a measure of the actual median *Ascaris* infective dose, but rather an empirical value arising from their statistical analyses [14].

The annual probability of infection, $P_{I(A)}(d)$ (pppy), is given by:

$$P_{I(A)}(d) = 1 - \left[1 - P_I(d)\right]^n \tag{2}$$

Where n is number of events per year to the single *Ascaris* dose (−) [14]. For norovirus, the dose response data set of Teunis et al. [1] was used in place of the β-Poisson equation [14]. The β-Poisson equation was used to assess the dose response of salmonellosis. The N_{50} and α used are 17,700 and 0.23475 respectively.

2.1.4. Exposure assessment

The human exposure assumed to take place is an event when farmers work on compost. Practically, one egg is enough to cause an infection. Norovirus has an extremely low infectious dose [9] and salmonellosis is a public health concern in Burkina Faso [2].

2.1.5. Risk characterisation

The Monte Carlo technique has been used to evaluate the infection risk. The random number is applied for estimation of variables with distributions for simulation of Eqs. (1) and (2). The simulation was repeated 10,000 times [14]. Then, 95 percentile of the probability was estimated as the infection risk.

3. Results and discussion

The temperature variation for 1 week was measured during February, 2015 in the post-treatment unit with the aid of ThermoManager sensors in Ouagadougou, Burkina Faso. The sensors recorded temperature data every five mins during the week. **Figure 3** shows the temperature pattern in the post-treatment unit. The maximum and minimum temperatures recorded from the bottom were 51.0 and 10.5°C. The middle recorded 50.0 and 9.5°C for maximum and minimum temperatures while the top recorded maximum of 78.5°C and a minimum of 6.5°C. Obviously, the lower temperatures were recorded in the night and high temperature during the day.

The estimated changes in concentration of *Ascaris* for the scenarios S1–4 are shown in **Figure 4**. The concentrations declined from the initial value of 336 eggs/g dry-compost. S1 with high

temperature gave high decline rate of the concentration due to high inactivation rate coefficient. Each scenario showed high and low reduction rates, because high temperature at day time and low temperature at night respectively. All scenarios for *Ascaris* obtained reduction

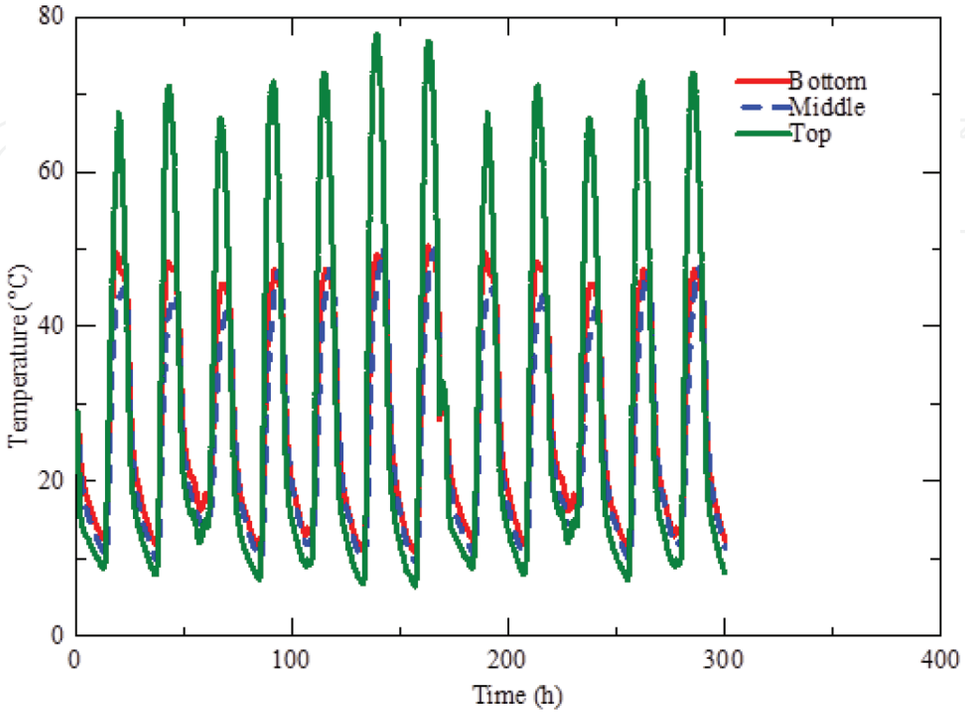


Figure 3. Temperature distribution assumed in the risk estimation.

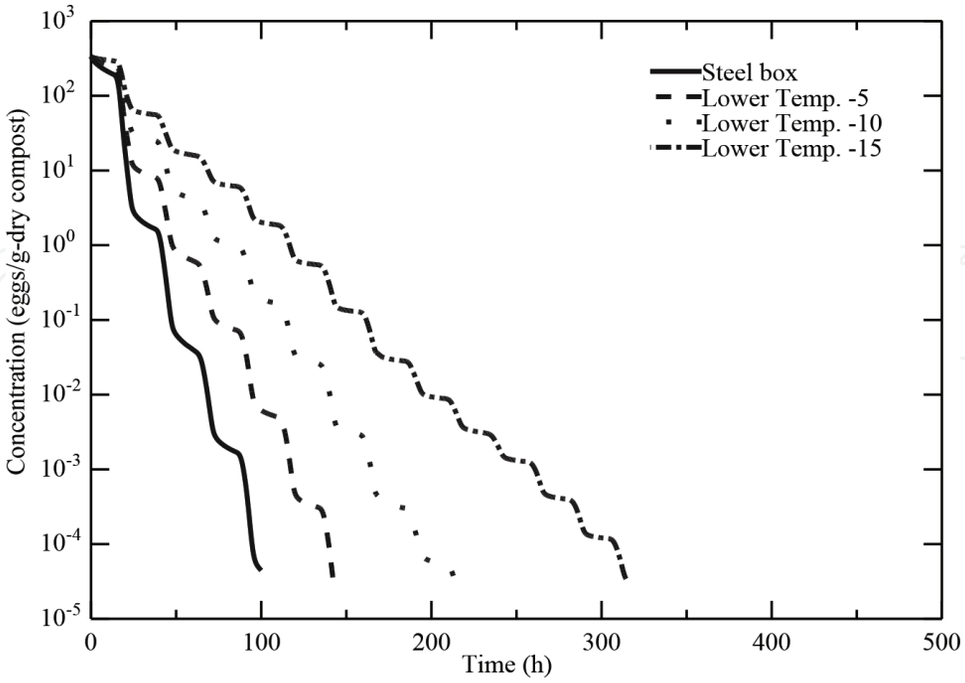


Figure 4. Change in *Ascaris* eggs concentration for the post-treatment.

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of eggs in 295 h and the differences of the temperature resulted in the differences in concentrations. The changes in concentration of norovirus with elapsed of time under all scenarios are shown in **Figure 5**. The concentration declined from the initial of 6.72×10^8 copies/g-dry

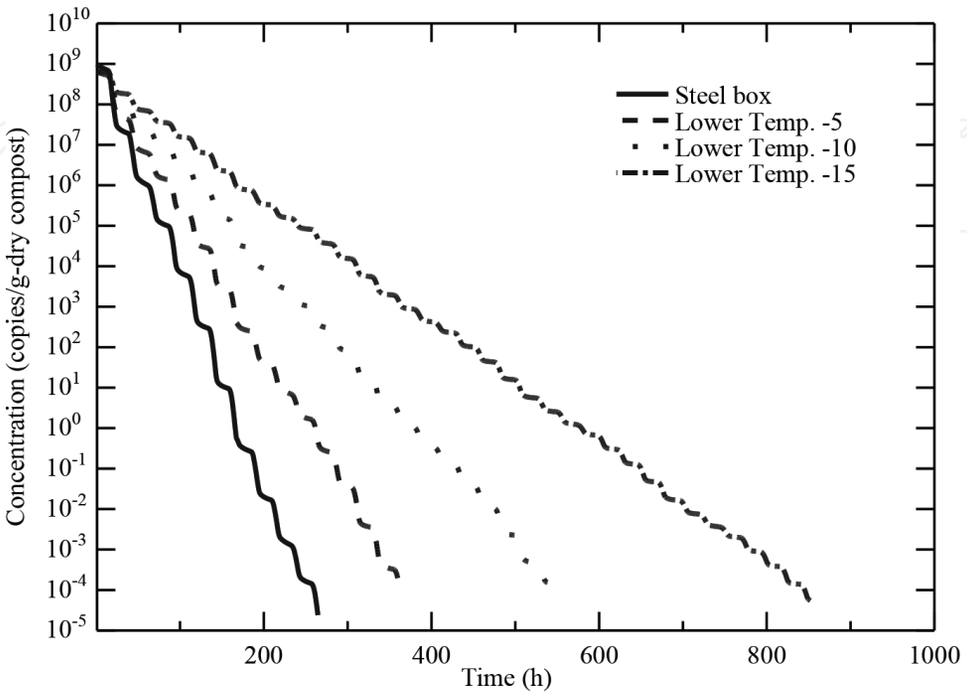


Figure 5. Change in norovirus concentration for post-treatment.

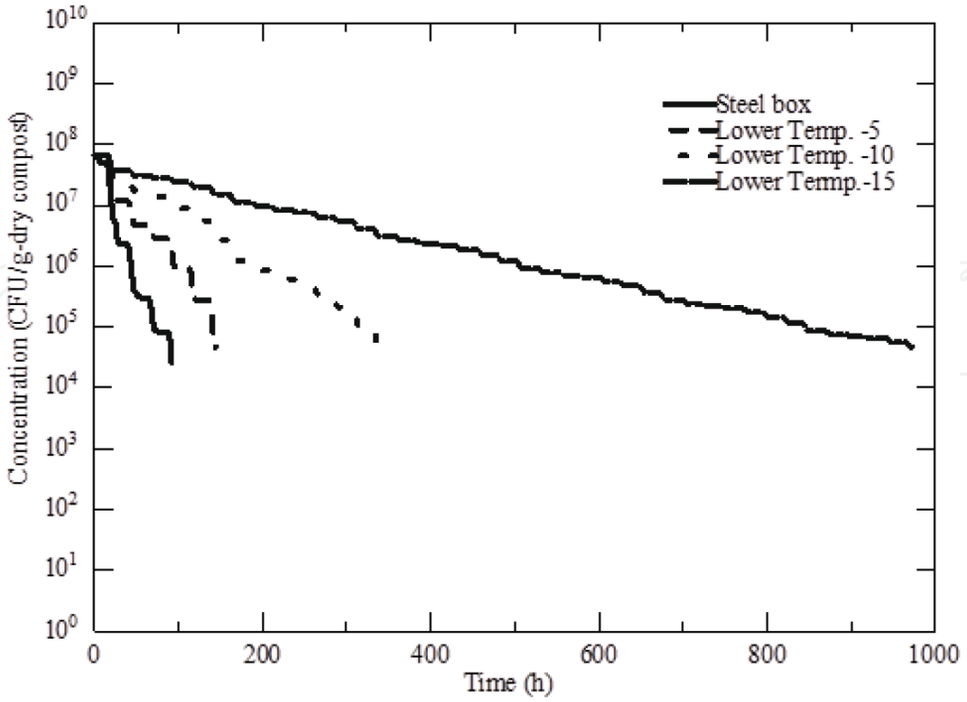


Figure 6. Change in *Salmonella* concentration.

compost. Higher temperature condition also gives higher decline rate. The reduction rate of norovirus concentration had difference among four scenarios like the *Ascaris* case. The concentration varied due to the varied temperature especially at night. As expected, the day time recorded higher temperatures and lower temperatures were recorded at night. All the scenarios achieved safe level at 845 h.

The change in concentration of *Salmonella* with elapse time under all scenarios are shown in **Figure 6**. The concentration declined from the initial of 6.72×10^7 CFU/g dry-compost. Higher temperature condition also gave higher decline rate. The reduction rate of *Salmonella* concentration had difference among four scenarios like the *Ascaris* and norovirus case. All scenarios achieved safe level at 969.5 h.

The 95-percentile annual risk of *Ascaris,* norovirus and *Salmonella* infections for the all scenarios are shown in **Figures 7–9**. The risk of the pathogens are almost 1 at the initial for all scenarios. This means the people who use the compost would be heavily polluted by the pathogens. They would be infected if the composting reactor fails to reduce the pathogen concentration and also if they do not apply the post-treatment. Schönning et al. [15] also reported a 95-percentile risk of rotavirus and *Ascaris* for 0 months' storage in a worst case as 1. The results show the risks for the *Ascaris* for S1 and the low temperatures as S2–4 reduced concentrations and reached a safe level at 97.5, 138, 190 and 295 h respectively.

The volume of the composting reactor is 100 L. Taking account of the temperature distribution with depth of the unit, the top and bottom temperature would achieve a safe level before the middle because that is the lowest temperature zone in the post-treatment unit. It should be noted that about 25% of the volume of the composting reactor was used for the design of the

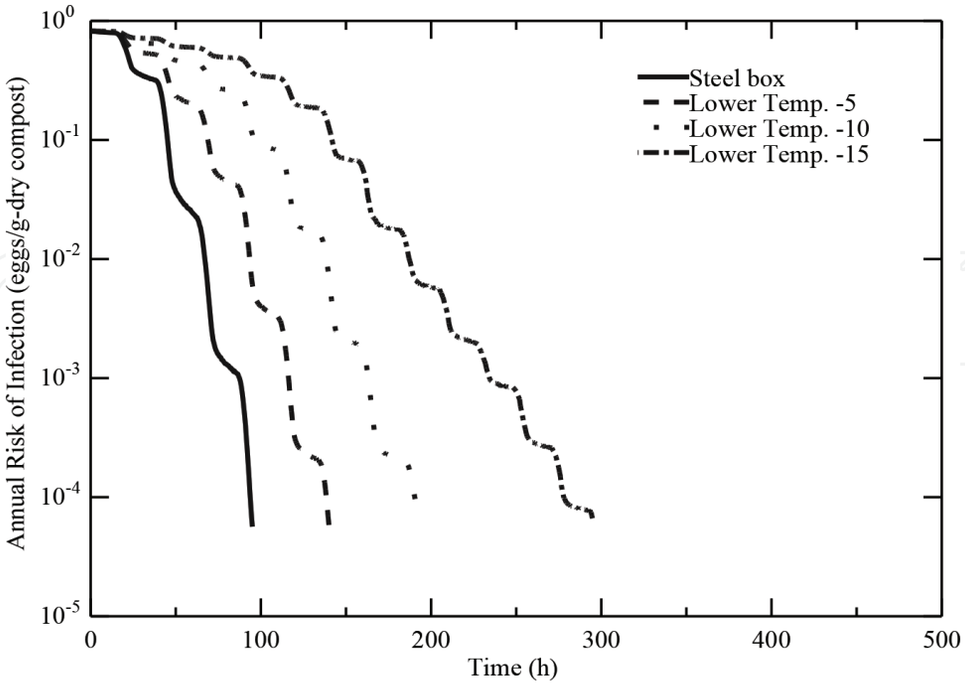


Figure 7. Ascaris annual infection risk associated with post-treatment.

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unit. This is to ensure that the unit is not too deep to reduce the efficiency of the unit. The unit is considered as a batch reactor (BR) where concentration of the compost would change with time. The expected concentration can be obtained by adjusting the reaction time. The temperature distributions in S1 recorded a shorter time than the other scenarios. The treatment time can be reduced if the heating process of the unit is improved. During the day, there is a sufficient increase in temperature, but it suddenly decreases towards the evening and at the nights. This phenomenon causes sufficient inactivation by the balance of the high inactivation rate at high temperature and the low inactivation at low temperature. To reduce treatment time, one needs to improve the post-treatment unit increasing the maximum temperature and keeping temperature during the night.

The required times to reach the safe level for norovirus for the scenarios S1–4 were 264, 362.5, 554 and 845 h respectively. And also the required times for *Salmonella* were respectively 90.5, 143, 356.5 and 969.5 h respectively. Comparing *Ascaris*, norovirus and *Salmonella*, *Salmonella* requires more time at lower temperatures than *Ascaris* and norovirus to reach safe level of 10^{-4} per person per year (pppy) [16]. This is probably due to the fact that lower temperature are favourable conditions for bacteria. Therefore, *Salmonella* is more important indicator for the design of the unit, even though *Ascaris* eggs have possibility to survive several months in a soil system [17].

Risk assessments for post-treatment of compost have received very little documentation. Seidu et al. [17] reported increased levels of *Ascaris* and rotavirus infection for farmers due to accidental ingestion of contaminated soils. The estimated median risk values for farmers were 0.99 and 7.2×10^{-2} pppy for Ascariasis and rotavirus. The study indicated that the elevated hazard posed by the soils on the farm could be attributed to the persistence of *Ascaris*

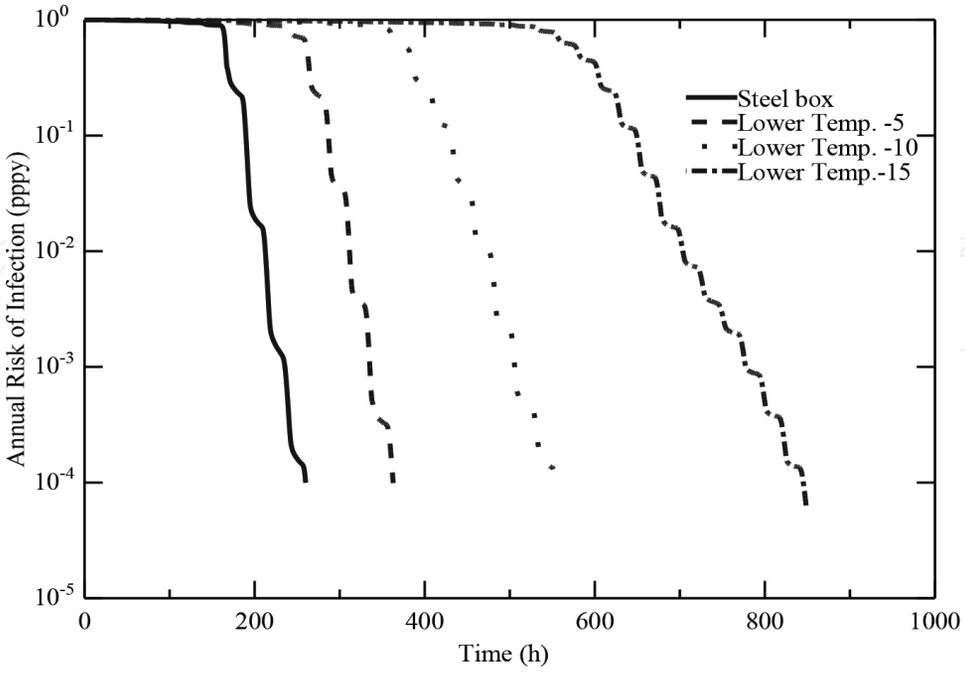


Figure 8. Norovirus annual infection risk with post-treatment.

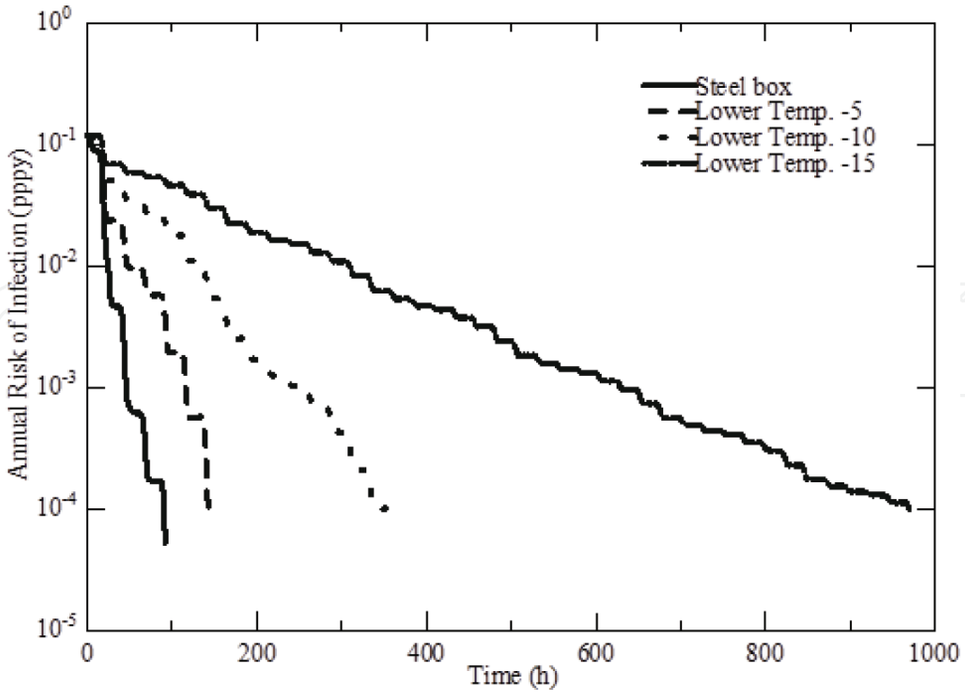


Figure 9. *Salmonella* annual infection risk associated with post-treatment.

in the soils. This implies that compost must be treated properly before reuse as fertiliser so as not to pose even greater risk in the soils. However, in semi-arid regions where the compost is expected to be used, inactivation of *Ascaris* occurs in soils rapidly [9] which indicates that post-treatment in these regions could be feasible. The results of this study indicate that high temperature with prolonged treatment time could reduce the hazard considerably. Mara et al. [14] reported risk of fieldworkers' involuntary ingestion of 100 mg of waste-water contaminated soils. The median of norovirus infection risk for an ingestion of 100–1000 mg, 10–100 mg, 1–10 mg of contaminated soil were 0.98, 0.32, and 3.7×10^{-2} pppy respectively. The study also reported the median *Ascaris* infection risk for ingestion of 100–1000 mg, 10–100 mg, and 1–10 mg of contaminated soils as 0.14, 1.5×10^{-2}, and 1.5×10^{-3} pppy respectively. In this study, the risk associated with the exposure of *Salmonella* at lower temperature was estimated to be the highest, thus, this level of pathogen reduction will provide sufficient protection against *Ascaris* and norovirus infections.

4. Conclusion

The temperature distribution in the steel box and the lower temperatures although reached a safe level, the time required for the safe treatment is too long and hence the steel box needs an improvement. Therefore, to efficiently reduce pathogens during the post-treatment and also reduce the time of treatment, the steel box needs an insulator to maintain the temperature. The guidelines for the design of the post-treatment facility are: For *Ascaris*, the steel box and the lower temperature −5, −10 and −15°C, post-treatment requires temperature between

78°C (maximum temperature during the day) − 6.5°C (min temperature during the night) and approximately time of 295 h to achieve the safe level of 10^{-4} pppy. For norovirus, post-treatment requires temperature from 78 to 6.5° and approximately time of 845 h for all the scenarios to achieve a safe level. *Salmonella* requires temperature range from 78 to 6.5°C and time of 969.5 h, for all scenarios to reach a safe level. The evaluation of the performance of post-treatment unit for risk assessment of the targeted pathogens has been achieved with the developed mathematical model.

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