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Fate of Pathogens in Sludge Sand Drying Beds at Qateef, Khobar and Dammam: A Case Study

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ABSTRACT: Due to uncontrolled dump of dried municipal sludge and its use by farmers as soil conditioner and/or fertilizer, an extensive research was conducted in order to determine the microbiological characteristics of municipal sludges produced at three major cities, namely, Qateef, Dammam and Khobar in the Eastern Province of Saudi Arabia. Sludge samples were collected, from sand drying beds, twice a season for one year and were analyzed for certain potential microbiological parameters such as *fecal coliform* and *salmonella*. The results indicated that municipal sludge produced at the three cities was not suitable for utilization in agricultural activities due to the high levels of *salmonella* even after 14 days of drying at Qateef wastewater treatment plant. Dried sludge samples collected from Qateef, Dammam and Khobar were found to contain *salmonella species* on the average of 22, 107 and 127 MPN per gram of dried sludge, respectively.

Key words: Municipal Sludge, Sand Drying Beds, Bacteria, Parasites, Sludge Reuse, Fecal Coliform, Salmonella, Qateef, Khobar, Dammam

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INTRODUCTION

In the Eastern Province of Saudi Arabia, sludge is not being characterized by the water and sewerage authority and is mainly disposed by a land spreading technique at sites outside the cities of Dammam, Khobar, and Qateef. Furthermore, farmers utilize municipal sludge which is transported to the farms without controlled drying period, proper characterization and treatment as a fertilizer and/or soil conditioner. This practice may result in crops that are polluted with pathogens, toxic organics, and heavy metals.The characteristics of sludge to be measured are strongly related to its ultimate fate. For example, if the sludge is to be thickened by gravity, its settling and compaction characteristics are important. With respect to microbiological characteristics of municipal sludges, wastewaters generally contain four major types of pathogens: bacteria, protozoa, viruses, and helminthes. The concentrations of these pathogenic organisms in wastewater depend on the health condition of the community. In times of epide-mics, these concentrations would be high. Since pathogens come from relatively large volumes of wastewater, when ending up in the sludge, they, in general, become concentrated and very infectious. (Gaspard, *et al.*, 1997) performed a parasitological analysis of helminthes on 89 sludge samples, three sediments, and seven composts. The average concentration of helminthes was 130 eggs per 100 gr. of dry matter, which was considered insignificant. Sludge from all types of treatment (mesophilic anaerobic and aerobic digestion, composting, and liming) contained 10 or more viable eggs per 100 gr. of dry matter. Antibiotic resistance of *Escherichia coli* in sludge and wastewater was affected by location but not the digestion process (Pillai, *et al.*, 1997). Fars, *et al.*, 2005, investigated the antibiotic resistance and survival of fecal coliforms in activated sludge process in a semi-arid region. They concluded that the treatment of sludge in drying beds appeared to be efficient in eliminating pathogenic microorganisms such as fecal coliform, protozoan cysts and helminth eggs. (Plachy and Juris, 1995) investigated the survival of helminth *ascaris-suum* eggs in the sludge drying beds of two sewage treatment plant. They concluded that the most important factors affecting the viability of the eggs at one of the treatment plants were exposure time and solid content, while other factors showed no statistically significant influence. Results of the other treatment plant showed that, besides exposure

time and solid content, sludge pH, drying bed temperature and air temperature were significantly affecting the viability of the eggs. Zaleski *et al.,* 2005, evaluated the potential for conversion of class B to class A biosolids with respect to *salmonella* and *fecal coliforms* when using solar drying in concrete lined beds. They concluded that numbers of *fecal coliforms* and *salmonella* decreased as temperature and rate of desiccation increased. Requirements of class A sludge were achieved after 3 to 4 weeks of drying. Gautam et al., 2005, implemented irradiation of municipal sludge for safe disposal and agricultural use. They reported that the process parameters were adjusted to effectively eliminate coliform bacteria in the sludge and to prevent their re-growth. Irradiated sludge was found to be free of *fecal coliform* and could be directly disposed after drying in a landfill or used as manure. (Sasakova *et al.,* 2005) investigated parasitological and bacteriological risks to animal and human health arising from waste-water treatment plants. They reported that no helminth eggs were found in effluents from the municipal wastewater treatment plant. Of 40 samples of sludge from the treatment plant, only two were positive for *ascaris spp*. and *trichuris spp*. eggs. (Thomaz-Soccol *et al.,* 1997) investigated the helminth eggs viability in sewage and biosolids sludge in Curitiba, Parana, Brazil. They reported parasitological analyses of twelve sludge biosolids and ten sewage sludge samples that were collected and analyzed for a period of one year. Four of the ten sewage sludge samples examined revealed the presence of helminth eggs as high as up to 20 per liter. In the biosolids sludge, the average number of helminth eggs, per 1 g of dry matter, was 4.85. However, the aerobic treatment reduced the viability of helminth eggs to 56.67 percent and the total number of viable eggs was 1.85 per gram of dry matter. *Ascaris sp.* was the prevalent parasite (75.7 percent), followed by H. diminuta (9.3 per cent), Trichuris sp. (7.4 percent), Hymenolepis nana (3.6 percent), Toxocara sp. (2.7 per cent), and Taenia sp. (1.3 percent). They concluded that treatment of the wastewater was found to be necessary to hygienize the sludge for use in agriculture. Therefore, to assess the environmental and health impact of municipal wastewater sludge, proper characterization must be first carried out in terms of microbiological, physical and chemical properties of the sludge. Based on the results of the characterization, alternative treatment processes should be evaluated and finally, proper reuse or disposal schemes be recommended. Sludge drying beds are physical treatment processes that can be considered as an effective way of sludge dewatering, however, the performance of these processes depend entirely on the physical condition of the bed, type of sludge, temperature, detention time (drying period) and meteorological conditions. Dharmappa *et al.,* 1997, reported that sand drying beds are popular due their reliability, ease of use and low cost. However, one of the basic concerns with sand drying beds is the requirement of a large area of land. Hossam *et al.,* 1990, assessed the drain ability of sludge generated by different treatment processes. They reported that the climatic conditions were generally favorable for dewatering sludge on sand drying beds except when there was heavy rainfall during wet seasons which resulted in prolonging the drying period. Al-Muzaini, 2003, investigated the performance of sand drying beds for sludge dewatering in Kuwait. He concluded that sand drying beds have become less popular as a dewatering system because they are subjected to uncontrolled conditions such as temperature, rainfall and sludge drainage rate. Based on the above discussion, the main objective of this research was to determine the fate of pathogens in municipal sludge of three main cities in the Eastern Province of Saudi Arabia.

MATERIALS & METHODS

Sludge samples collected from the sand drying beds of Khobar, Dammam, and Qateef wastewater treatment plants were characterized by determining their microbiological properties, as shown in Table 1. Sludge sampling was carried out twice per season. When the drying period was seven days, as in the case of Dammam and Khobar, samples were collected at the interval of 0, 1, 2, 4 and 7 days. However, when the drying period was fourteen days, as in the case of Qateef, samples were collected at the interval of 0, 2, 5, 10 and 14 days. Five core samples were collected from pre-assigned beds; four from each corner and one from the middle and were delivered to the Environmental Engineering Laboratories at King Fahd University of Petroleum & Minerals for analysis. The five core samples were then homogenized in order to constitute one representative sludge sample. Standard methods were implemented in the sample analysis. It is worth to mention that collected sludge samples were analyzed in triplicates. The following is a brief description of the techniques which were employed in determination of different microbiological parameters: Presumptive lauryl sulfate MPN test was used followed by BGB

confirmed test.Also, and direct enumeration was done by Membrane Filter technique using M-Endo agar.

Table 1.Microbiological parameters

Bacteria
• Coliforms - Escherichi coli
• Streptococcus sp.
• Salmonella sp.
• Shigella sp.
• Clostridium perfringens
Parasites
• Entamoeba histolytica
• Ascaris lumbricoides
• Ancylostoma duodenale
• Hymenolepis nana
• Trichuris trichura
• Enterobius Vermicularis

Presumptive positive samples were inoculated in EC medium to confirm quantitatively *fecal coliforms* from total *coliforms*. Inoculationn of samples into azide dextrose broth and incubatin at 35°C for observing turbidity for the presence of *Streptococcus sp.was erformed.* Confirmation was done by streaking PSE agar for brown positive colonies. Xylose lysine desoxycholate (XLD) agar was used for primary isolation of *Shigella sp.* Strains. Incubation at 35 °C for 24 h. Was also performed for isolation of red positive colonies. Samples were inoculated in clostridium basal media and incubated at 37 °C to detect positive black *Clostridium perfringens* colonies. Using zinc sulfate floatation technique, all the existing helminthic types were identified. Both protozoan and helminthic parasites are expected to be present in the sludge. The main helminthic parasites present as ova of human enteric species are represented by *Ascaris lumbricoides, Enterobious vermicularis, Ancylostoma doudenale, Trichuri trichura and Hymenolepis nana*. The main enteric protozoan parasite includes *Entamoeba histolytica*. Two techniques were used for detection and enumeration of helminthic and protozoan parasites, namely floatation and sedimentation. Sedgewick-Rafter cell was used for quantitative analysis. Suspensions were strained through 7-10 μm membrane and resuspended. Sedgewick-Rafter cell was used in enumeration (Concentration Method).

RESULTS & DISCUSSIONS

In this section, data obtained on sludge microbiological characteristics for samples collected from the three cities during the first and second sessions of the four seasons will be presented. However, due to similarities in result patterns obtained on individual microbiological parameters, only part of the results will be presented graphically and discussed.A major environmental concern associated with municipal sludge handling is the effect of pathogens on public health and animals. Kowal, 1985, reported those pathogens of concern in municipal sludge and their associated health effects. Table 2 shows some disease-producing protozoa and helminthes which were reported to be encountered in wastewater and municipal sludges, while Table 3 shows the levels of certain indicator and pathogenic organisms in municipal sludges. Furthermore, the survival times of some pathogens in soil and on plant surfaces are shown in Table 4 (EPA, 1992). Tables 5, 6 and 7 show the statistical analysis of data obtained on raw and dried sludge samples collected from Qateef, Dammam and Khobar, respectively. Minimum, maximum, mean, and standard deviation of microbiological parameters are presented in the Tables. On the other hand, Table 8 shows a summary of the mean values of general microbiological characteristics of dried sludge samples collected from the three cities throughout the study period. It is worth to mention that *fecal coliform* and *salmonella* are expressed in MPN per gram of dried solids, while *streptococcus, shigella, and clostridium* are expressed in colonies per gram of dries solids. Regarding the microbiological quality of dried sludge samples collected from the three cities, Table 8 shows that *fecal coliform* density ranged between 4.97×10^5 and 2.11×10^6 MPN per gram of dried sludge, which is less than that reported by Kiely, 1997, for secondary untreated sludge (10^7 to 10^8). Similarly, *salmonella* species were found to range between 22 MPN per gram of dried sludge (in Qateef samples) to 127 MPN per gram of dried sludge (in Khobar samples). According to the U.S.EPA regulations, class A sludge should have either *fecal coliform* density under 1000 MPN per gram of dry solids or *salmonella* species density under 3 MPN per 4 grams of dried solids, while class B sludge should have *fecal coliform* density under 2×10^6 MPN per gram of dry solids (EPA, 1993). From the results on *salmonella*, it is clear that dried sludge from the three cities can not be considered as class A sludge and, therefore, can not be applied to lawn or home garden. Results on parasites in dried sludge collected from the three cities showed that all parasites under investigation were less than 1 per gram of dried solids. With respect to graphical representation of the fate of pathogens in sand drying beds, Figs. 1 and 2 show f*ecal coliform* in sludge samples collected from Qateef, Dammam, and Khobar.

Table 2. Pathogenic organisms in wastewater and sludge (EPA, 1992)

Organism	Disease/symptoms
Protozoa	Gastroenteritis
Cryposporidium	Acute enteritis
Entamoeba histolytica	Giardiasis
Giardia lamblia	Diarrhea and dysentery
Balantidium coli	Toxoplasmosis
Toxoplasma gondii	
Helminths	
Ascaris lumbricoides	Digestive and nutritional disturbances; abdominal pain, vomiting
Ascaris suum	May produce symptoms such as coughing, chest pain, and fever
Trichuris trichiura	Abdominal pain, diarrhea, anemia, weight loss
Toxocara canis	Fever, abdominal discomfort, muscle aches, neurological symptoms
Taenia saginata	Nervousness, insomnia, anorexia, abdominal pain, digestive disturbances
Taenia solium	Nervousness, insomnia, anorexia, abdominal pain, digestive disturbances
Necatur americanus	Hookworm disease
Hymenolepis nana	Taeniasis

Table 3. Levels of indicator and pathogenic organisms in different sludges (per gram of dry weight) (Kiely, 1997)

Sludge (untreated)	*Total Coliform*	*fecal Coliform*	*Fecal Streptococci*	*Salmonella species*	*Pseudomonas aeruginosa*	Enteric viruses
Primary	10^6-10^8	10^6-10^7	10^6	4×10^2	3×10^3	0.002-0.004
Secondary	10^7-10^8	10^7-10^9	10^6	9×10^2	1×10^4	0.015-0.026
Mixed	10^7-10^9	10^5-10^6	10^6	5×10^2	10^3-10^5	--

Table 4. Survival times of various pathogens in soil and on plant surfaces (EPA, 1992)

Pathogen	SOIL		PLANTS	
	Absolute Maximum	Common Maximum	Absolute Maximum	Common Maximum
Bacteria	1 year	2 months	6 months	1 month
Viruses	6 months	3 months	2 months	1 month
Protozoan cysts	10 days	2 days	5 days	2 days
Helminth ova	7 years	2 years	5 months	I month

Table 5. Statistical analysis of Qateef data

Parameters	Raw Sludge				Dried Sludge			
	Min.	Max.	Mean	Std. Deviation	Min.	Max.	Mean	Std. Deviation
Fecal Coliform	1.4E+08	2.4E+08	2.1E+08	34846603	9.0E+04	2.4E+06	4.87E+5	850602
Streptococcus	3.4E+06	4.0E+06	3.73E+06	305505	3.4E+03	4.2E+03	3.87E+03	416
Shigella	5.9E+03	6.1E+03	6.0E+03	100	15	33	23	9
Salmonella	4.5E+03	5.0E+03	4.8E+03	265	5	50	22	25
Clostridium	6.0E+04	7.5E+04	6.83E+04	7638	170	500	300	176
Ascaris	4	91	67	30	0	1	0	0
Trichuris	0	50	29	21	0	0	0	0
Hymenolepis nana	0	0	0	0	0	0	0	0
Entaamoeba histolytica	0	91	28	36	0	0	0	0

Table 6. Statistical analysis of Dammam data

Parameters	Mean Values		
	Qateef	Dammam	Khobar
Fecal Coliform (MPN/g)	4.87E+5	2.11E+06	4.97E+05
Streptococcus (Colony/g)	3.87E+03	2.99E+03	1.37E+03
Shigella (Colony/g)	23	157	177
Salmonella (MPN/g)	22	107	127
Clostridium (Colony/g)	300	3900	3900
Ascaris (Parasite/g)	0	0	0
Trichuris (Parasite/g)	0	0	0
Hymenolepis nana (Parasite/g)	0	0	0
Entaamoeba histolytica (Parasite/g)	0	0	0

Table 7. Statistical analysis of Khobar data

Parameters	Raw Sludge				Dried Sludge			
	Min.	Max.	Mean	Std. Deviation	Min.	Max.	Mean	Std. Deviation
Fecal Coliform	1.6E+08	4.1E+08	3.0E+08	105356538	3.0E+04	1.3E+07	2.11E+06	4814671
Streptococcus	9.6E+05	4.0E+06	1.99E+06	1743713	9.6E+02	7.0E+03	2.99E+03	3476
Shigella	4.9E+03	5.3E+03	5.07E+03	208	100	260	157	90
Salmonella	6.8E+03	7.0E+03	6.93E+03	115	100	110	107	6
Clostridium	5.0E+04	6.1E+04	5.37E+04	6351	3600	4100	3900	265
Ascaris	0	101	29	40	0	1	0	0.5
Trichuris	0	42	15	19	0	0	0	0
Hymenolepis nana	0	3	0	1	0	0	0	0
Entaamoeba histolytica	0	121	32	45	0	1	0	0

Table 8. General characteristics of dried sludge collected from three cities of the Kingdom

Parameters	Raw Sludge				Dried Sludge			
	Min.	Max.	Mean	Std. Deviation	Min.	Max.	Mean	Std. Deviation
Fecal Coliform	1.4E+08	4.0E+08	2.39E+08	90079330	4.0E+04	1.1E+06	4.97E+05	418000
Streptococcus	2.1E+06	3.6E+07	1.4E+07	19100349	5.0E+02	2.0E+03	1.37E+03	777
Shigella	5.0E+03	6.0E+03	5.6E+03	529	140	210	177	35
Salmonella	3.2E+03	3.9E+03	3.5E+03	361	110	140	127	15
Clostridium	5.0E+04	5.9E+04	5.5E+04	4583	2800	5000	3900	1100
Ascaris	3	178	60	55	0	1	0.	0.5
Trichuris	0	26	9	11	0	0	0	0
Hymenolepis nana	0	0	0	0	0	0	0	0
Entaamoeba histolytica	4	70	46	21	0	1	0	0

Generally, the figures show that *fecal coliform* was decreasing in sludge samples, with respect to drying period. In Qateef samples, the initial *fecal coliform* count was 1.4-2.4 $\times 10^8$ MPN per gram of dry sludge, which was seen to decrease and reach a value of 4×10^5 - 2.4×10^6 MPN per gram of dry sludge after 14 days of drying. Similarly, Dammam and Khobar sludge samples contained initial *fecal coliform* counts of 1.6-2.3 $\times 10^8$ MPN per gram of dry sludge, respectively, which decreased to 1.3×10^7 and 6×10^6 MPN per gram of dry sludge, respectively, after seven days of drying period during the first session. Protozoan and helminthic pathogens are of great concern due to their probable effects on the public health. Sludge samples from Qateef, Dammam, and Khobar were examined for helminthic and protozoan pathogens such as *Ascaris lumbricoides, Enterobious vermicularis, Ancylostoma doudenale, Trichuri trichura, Hymenolepis nana*, and *Entamoeba histolytica*. The results showed that all sludge samples, from the three different cities, were free from *Enterobious vermicularis, Ancylostoma doudenale, and Hymenolepis nana*.

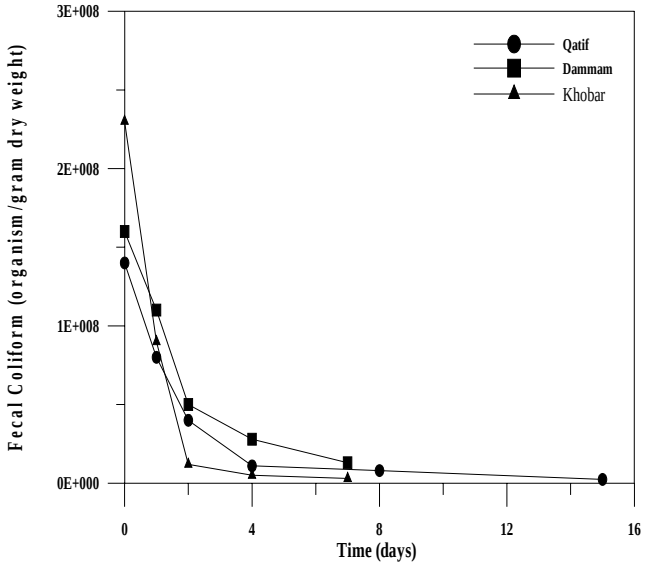

Fig. 1. *Fecal Coliform* with respect to drying time during the first session

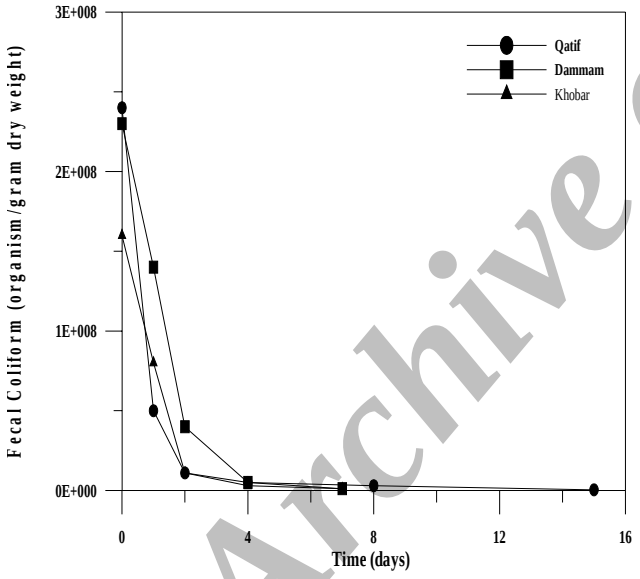

Fig. 2. *Fecal Coliform* with respect to drying time during the second session

Regarding *Ascaris lumbricoides*, Figs. 3 and 4 show that those parasites were decreasing with respect to drying period in sludge samples collected from the three cities during the first and second sessions, respectively. The figures also show that Khobar sludge was containing the highest number of *Ascaris lumbricoides* among other samples during the first session. In Qateef sludge, *Ascaris lumbricoides* were initially 68 parasites per gram of dry sludge and were found to decrease to one parasite at the end of the 14-day drying period. Dammam and Khobar samples contained initial

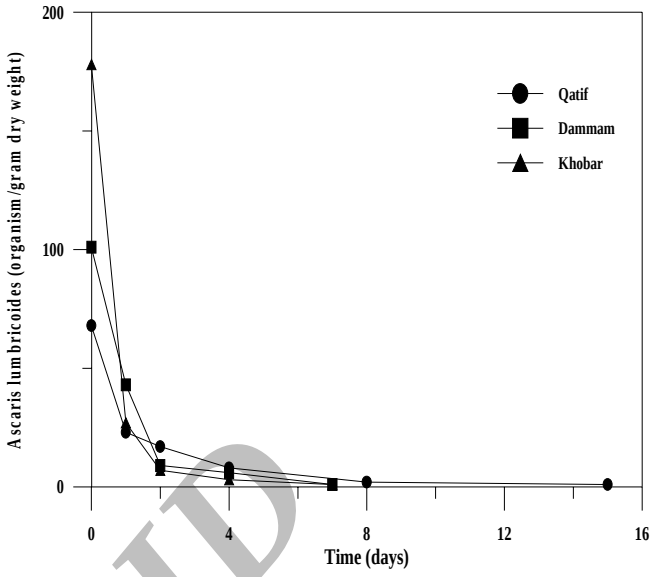

Fig. 3. *Ascaris* with respect to rying time during the first session

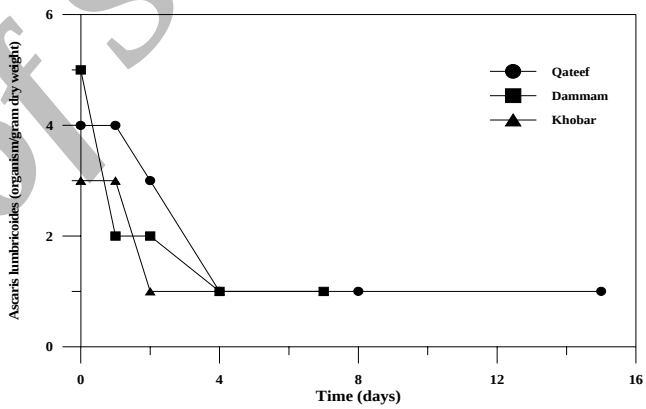

Fig. 4. *Ascaris* with respect to drying time during the second session

values of 101 and 178 parasites per gram of dry sludge, respectively, and were found to decrease to one parasite after seven days of drying. The figures also demonstrate that the maximum rate of decrease in *Ascaris lumbricoides* was taking place during the first two days of drying. This could be attributed to the fact that water infiltration is maximum at the start of the drying time, which may result in washing out those parasites from the sludge.Figs. 5 and 6 show the content of *Trichuri trichura* in sludge samples collected from the three wastewater treatment plants during both sessions. Qateef samples show that *Trichuri trichura* was detected in the first sample only. The initial counts of *Trichuri trichura* in Qateef sludge were 2 and 23 per gram of dry sludge. In Dammam sludge samples, the initial counts of *Trichuri trichura* were 1 and 40 per gram of dry sludge, which was found to decrease to five after two days of drying.

Thereafter, *Trichuri trichura* was not detected in Dammam sludge samples. Moreover, Khobar sludge samples were initially free of *Trichuri trichura* and remained so till the end of the drying period, during the first session. Pathogenic protozoa include *Entamoeba histolytica, Giardia lamblia, Balantidium coli* and *Cryptosporidium*. On a worldwide basis, *Entamoeba histolytica* infections are most common (Droste, 1997). The contents of the protozoan parasite *Entamoeba*

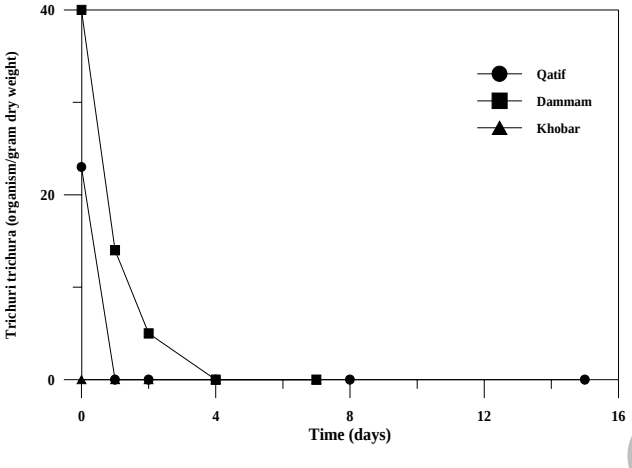

Fig. 5. *Trichuri trichura* with respect to drying time during the first session

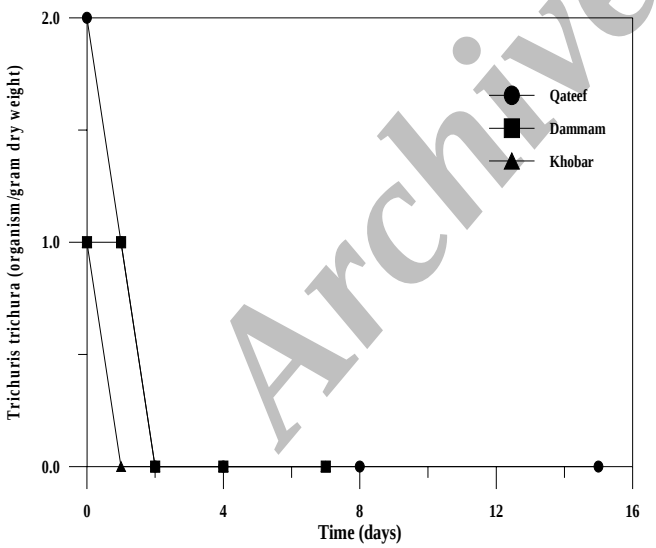

Fig. 6. *Trichuri trichura* with respect to drying time during the second session

histolytica in sludge samples collected from Qateef, Dammam, and Khobar are shown in Fig.s 7 and 8.In Qateef sludge samples and during the first session, *Entamoeba histolytica* was detected only in the first sample at a count of 45 per gram of dry solids. In sludge samples collected from Dammam wastewater treatment plant, *Entamoeba histolytica* initial count was 121 per gram of dry sludge, and was found to reach one per gram at the end of the drying time. Khobar sludge samples initially contained 59 *Entamoeba histolytica* parasites per gram of dry solids, which was reduced to three per gram after two days of drying. Thereafter, Khobar sludge samples were found to be free of *Entamoeba histolytica*. The results on sludge samples collected from the cities of Qateef, Dammam, and Khobar were almost free from helminthic and protozoan pathogens at the end of the drying period. Since the resistance of helminthic pathogens to environmental conditions is much higher than that of bacteria, the results may suggest that infiltration is the predominant removal mechanism of helminthic pathogens under investigation.In order to investigate the seasonal effect on the characteristics of dried sludge samples collected from the three cities, a comparison between results obtained over the course of investigation was made by presenting data obtained on total solids content and the survival of *fecal coliform*. Ambient minimum, maximum, and mean temperatures obtained from Dhahran station during all seasons are shown in Table 9 (PME, 2000). The table clearly shows that the mean ambient temperature recorded during spring summer, fall, and winter were 31.8, 36.8, 32 and 22.8 °C, respectively. Table 10 shows the seasonal effect on the contents of total solids and *fecal coliform* in dried sludge samples collected from Qateef, Dammam and Khobar. With respect to total solids in dried sludge and beside the effect of the physical conditions of drying beds, the table clearly demonstrates the seasonal effect on the contents of total solids.

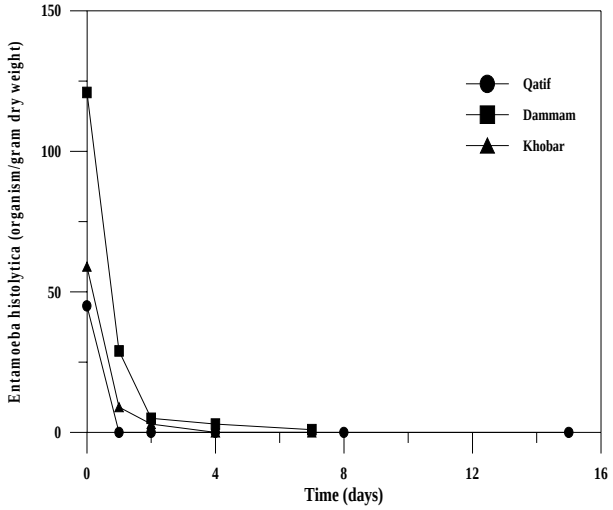

Fig. 7. *Histolytica* with respect to drying time during the first session

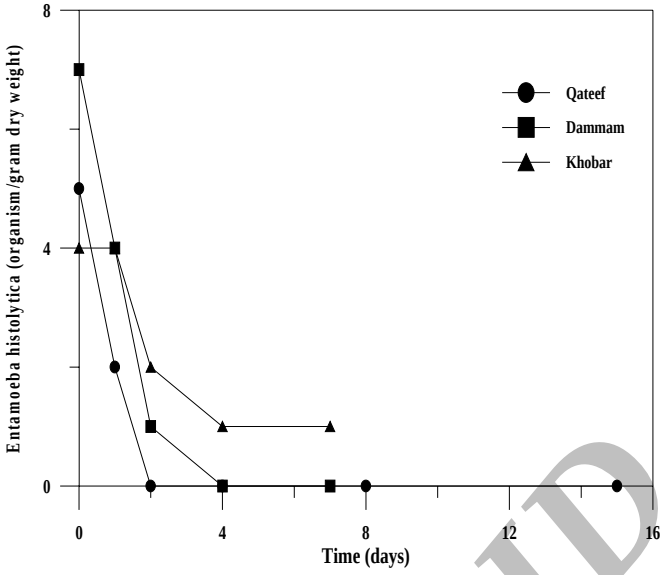

Fig. 8. *Histolytica* with respect to drying time during the second session

Table 9. Ambient minimum, maximum, and mean temperatures of Dhahran station

Season	Session	Ambient Temperature (^{o}C)			Season's Mean Temperature (^{o}C)
		Minimum	Maximum	Mean	
Spring	1	21.5	36.3	28.75	31.82
	2	27.7	42.2	34.9	
Summer	1	28.9	45.1	37	36.75
	2	29.5	43.5	36.5	
Fall	1	28	40	32	32
	2	--	--	--	
Winter	1	17	24	21.6	22.8
	2	18	27	24	

Table 10. Seasonal effect on total solids and Fecal Coliform in dried sludge

City	Parameters	Session	Season			
			Spring	Summer	Fall	Winter
Qateef	Total Solids %	1	80.42	85.7	89.92	41.7
		2	87.4	88.2	--	47.4
	Fecal Coliform / gram	1	2.40×10^{6}	1.7×10^{5}	1.1×10^{5}	5.4×10^{7}
		2	4×10^{5}	1.1×10^{7}	--	5.2×10^{7}
Dammam	Total Solids %	1	71.2	55.3	49.1	27.6
		2	57.7	59.4	--	42.2
	Fecal Coliform / gram	1	1.30×10^{7}	2×10^{5}	1.1×10^{5}	7.4×10^{7}
		2	1.1×10^{6}	1.1×10^{5}	--	7.1×10^{7}
Khobar	Total Solids %	1	54.8	50.9	51.1	34.6
		2	51.6	55.2	--	31
	Fecal Coliform / gram	1	3.00×10^{6}	6×10^{5}	3×10^{5}	5×10^{7}
		2	1.1×10^{6}	4×10^{4}	--	$4.8*10^{7}$

As an example of the first session, Qateef sludge was found to contain the lowest percentage of total solids during the winter season (42 percent), while the highest percentage was obtained during summer and fall seasons (80 and 90 percent). Regarding the *fecal coliform* in dried sludge samples collected from the three cities, the table clearly shows that as the ambient temperature decreases the density of *fecal coliform* increases. In all sludge samples, the winter samples were found to contain the highest densities of *fecal coliform*. As shown before, the increase in ambient temperature results in increasing the rate of evaporation, which in turn increases the content of total solids in sludge samples. Moreover, the increase in ambient temperatures will also result in increasing the rate of disinfection or inactivation of microorganisms in sludge samples**.**

CONCLUSION

Sludge samples collected from the three cities were examined for their microbiological characteristics. The results showed that dewatered sludge samples contained high densities of *fecal coliform* at densities ranging between 4.8×10^5 and 2.1×10^6 MPN per gram of dried solids. Pathogens such as *streptococcus*, *shigella*, *salmonella*, and *clostridium* were also detected in the samples of dried sludge collected from the three cities. Densities of *streptococcus*, *shigella*, *salmonella*, and *clostridium* were in the ranges of 1.4×10^3 to 3.9×10^3 colonies per gram of dried solids, 23 to 177 colonies per gram of dried solids, 22 to 127 MPN per gram of dried solids and 300 to 3900 colonies per gram of dried solids, respectively. On the other hand, dried sludge samples collected from the three cities were found to be free of protozoan and helminthic pathogens. The effect of seasonal ambient temperature on the inactivation of microorganisms was also investigated. The results showed that the rate of inactivation was higher during summer season. As an example, dried sludge samples collected from Khobar contained *fecal coliform* densities of 3.0×10^6, 6×10^5, 3×10^5 and 5×10^7 MPN per gram of dried solids during spring, summer, fall and winter, respectively.

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