Inorganic binder system to minimize emissions, improve indoor air quality, purify and reuse of contaminated foundry sand

LIFE17 ENV/FI/173 “Green Foundry LIFE”

Action B4.1.

Cleaning by composting method:

Results of summer tests in 2019

DeB.4A Composting method results of inorganic and organic binder system surplus sands in Finland

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Contents

Abbreviations

BOD	Biochemical oxygen demand
BTEX	Benzene, toluene, ethylbenzene, and xylenes
COD	Chemical oxygen demand
DOC	Dissolved organic carbon
PAH	Polycyclic aromatic hydrocarbons
PCB	Polychlorinated biphenyls
Phenol index	Includes phenol compounds analysed by method SFS-EN ISO 14402:en, Water quality – Determination of phenol index by flow analysis (FIA and CFA) (ISO 14402:1999)
TOC	Total organic carbon

1 Introduction

The main objective of the Green Foundry project is to decrease the environmental impact of the European foundry industry by introducing new clean technology systems in practice. By introducing inorganic binders in iron and steel foundries the aim is to reduce emissions and improve indoor air quality in ferrous foundries. The piloted technologies are feasible and transferable aiming to wide scale implementation in foundry industry across Europe.

In this project the inorganic binder system will be demonstrated and tested in iron and steel foundries. Also different surplus foundry sand purification and reuse methods will be demonstrated to reduce the amount of waste sand and create new reuse applications for surplus foundry sand.

One of the reuse applications is cleaning the waste sand by composting method (Action B4.1 Cleaning by composting method). This method has been piloted in previous Foundrysand LIFE project (LIFE13 ENV/FI/285) and results were promising. Composting tests are carried out in Finland and Spain to study the impact of different climate conditions in composting process. Both organic and inorganic sand specimens are tested.

Organic binders are almost exclusively synthetic resins which are cured by the addition of a separate hardener or catalyst. Inorganic binders are based on sodium silicates. Combinations of foundry sand with animal manure or other organic waste sludges will be made and the different material mixtures will be carefully studied and monitored to find out the most effective way of handling and cleaning the foundry waste sand. The process will be steered in a direction that useful humus occurs with good fertilizing abilities. The end-product must meet the national regulations and limit values.

In Finland altogether 6-8 pilot test heaps with different surplus foundry sands and dust specimens will be tested during the project. Based on Foundrysand LIFE project results it is expected that the hazardous organic compounds (like phenols, BTEX, PAHs) are to be cleaned with the efficiency of about 95% and the end-products can be used as mixture soil materials in geo-construction, road construction and green construction applications.

The environmental permit was applied from the Centre for Economic Development, Transport and the Environment in Pirkanmaa. Composting tests were carried out during 07/2019-11/2020. Composting tests were carried out at the waste treatment center Tarastenjärvi in Tampere.

First two test heaps of organic binder system waste sand and dust were started on 24th of July 2019 and ended on 11th of June 2020. Third composting test heap of inorganic binder system waste sand was constructed on 11th of June 2020 and ended on 18th of November 2020.

During the composting tests samples were collected from composting materials and waste waters and analysed by Eurofins Viljavuuspalvelu Ltd. Composting test heaps were constructed by Meehanite Technology Ltd and recipes are by Meehanite. Results of the composting tests in Finland are presented in this report.

2 Composting process

The degradation of organic material is rather fast in the beginning of the composting because there are plenty of nutrients present that are used as energy resource by the microbes. Heating of the compost is the result from the thermal energy production of microbes. Easily degradable components will degrade first and badly degradable components, like cellulose and lignin, will degrade at the latter part of the composting process. The activity of microbes in the compost decreases when the amount of nutrients decrease and this can be established by cooling of the compost. The composting process itself continues longer and the degradation of compost will become even. This stage is called the stabilization. Several chemical and physical reactions occur parallel with the degradation of organic compounds. By measuring and following these reactions relevant information of the composting progress and maturity will be gathered, see figure 1 (the original figure in Finnish, VTT 2006).

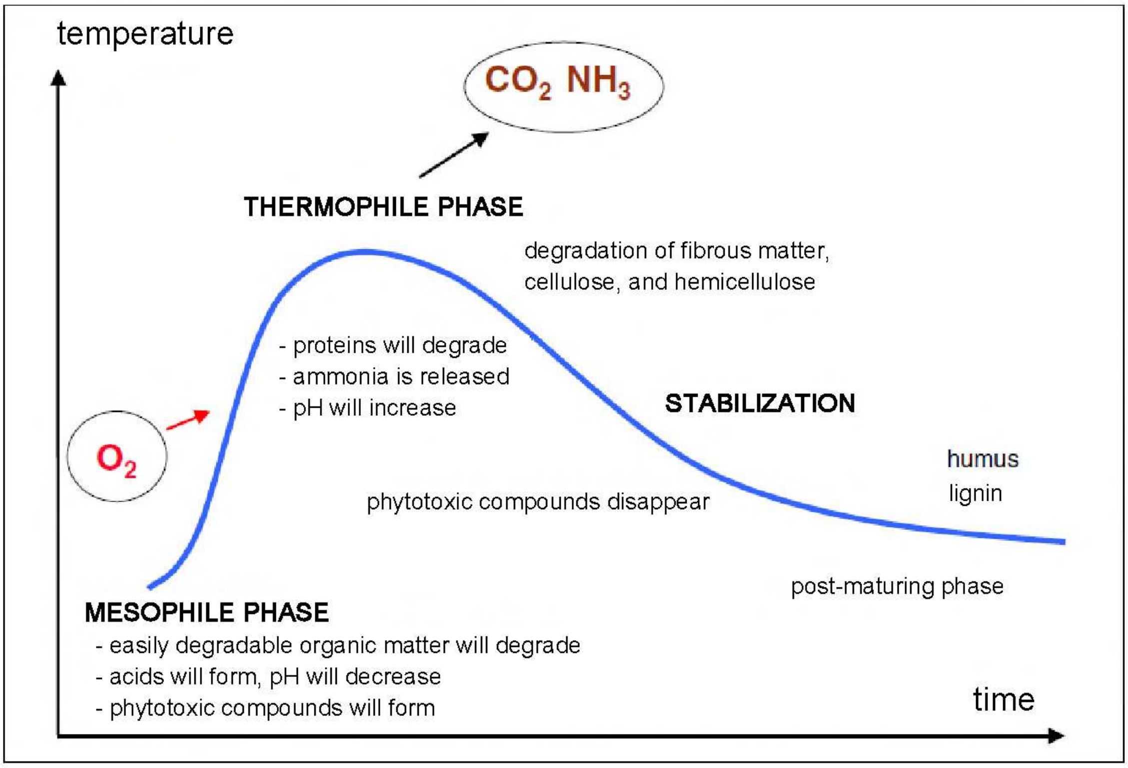

Figure 1. Different stages of the composting process (VTT 2006).

Requirements for the maturity and stabilization of the composting end-product are set in the Decree of the Ministry of Agriculture and Forestry on Fertiliser Products (24/2011). Once the requirements are fulfilled the composting end-product can be used as growing media ("Mixture soil") in Finland. These requirements and limit values will be followed in this Green Foundry LIFE project.

3 Composting tests in 2019-2020

The environmental permit for LIFE project composting tests at Tarastenjärvi solid waste treatment center, Tampere, was received on 7th of July 2019 from the Centre for Economic Development, Transport and the Environment in Pirkanmaa, Finland.

First two test heaps were constructed at Tarastenjärvi pilot site (see figure 2). Test heaps were made by Meehanite Technology Ltd. Meehanite and AX-LVI Consulting Ltd were responsible for the sampling procedure from composting materials and waste water effluents. Chemical and biological analyses were carried out by Eurofins Viljavuuspalvelu Ltd.

The size of each test heap was about 20 tons. The portions of surplus foundry sand in heaps varied between 25-30%. *In these heaps organic binder system phenolic sand and dust were used.* Other organic materials e.g. wood chips and animal manure were added. The construction of the heaps is presented in figures 3 and 4.

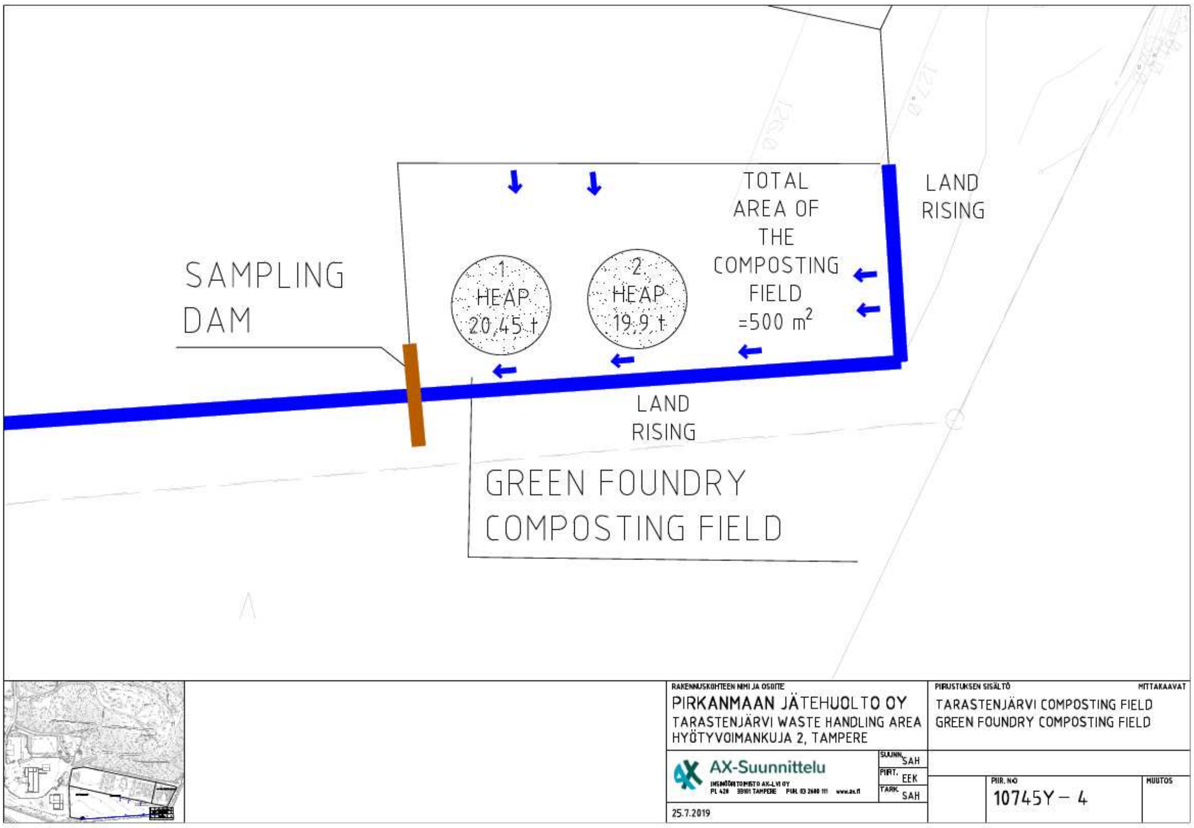

Figure 2. Composting test heaps at Tarastenjärvi in Tampere.

Figures 3. Constructing the test heaps in July 2019.

Figures 4. Pipelines for the aeration and heating systems were installed.

4 Monitoring the progress of composting tests and sampling procedures

The progress of the composting process was controlled by measuring temperature continuously.

Temperatures raised rapidly to almost 70 degrees after starting the composting tests (figures 5 and 6). The temperatures were well above 60 degrees in the beginning and stayed for over 2 months from July – September. According to the decree of 24/11 the temperatures should stay over 55 degrees for 14 days. The results demonstrate efficient composting process.

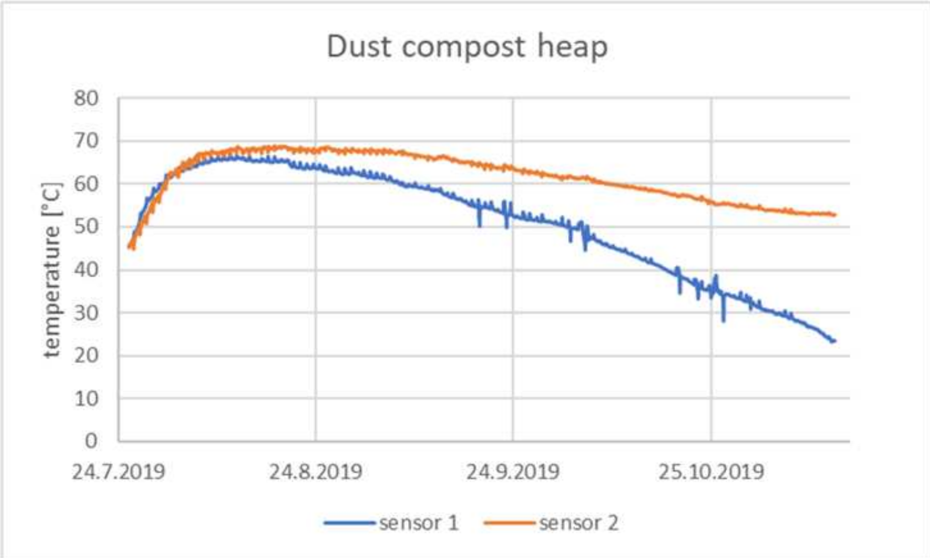

Figure 5. Temperature changes in dust compost test heap in two different depths in July-November 2019.

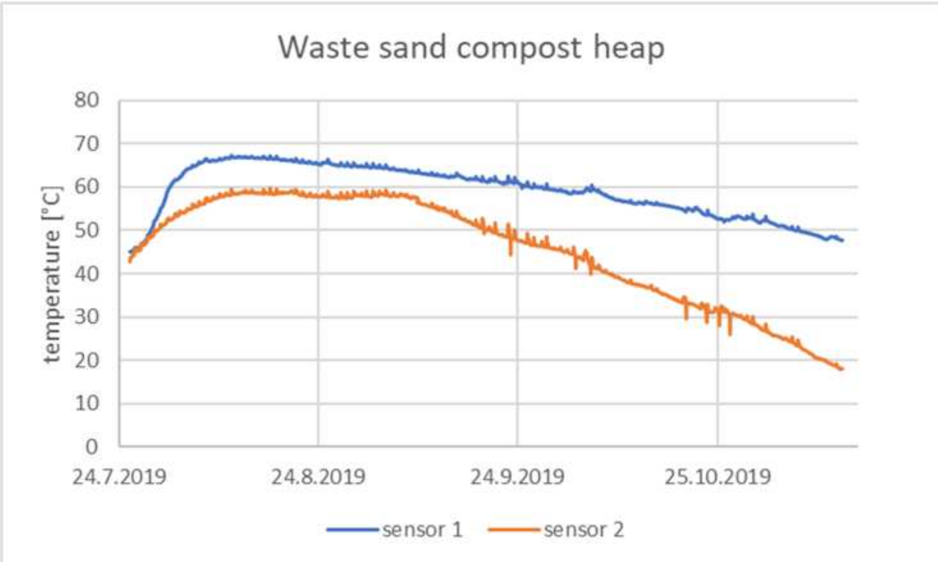

Figure 6. Temperature changes in waste sand compost test heap in two different depths in July-November 2019.

Composting material analyses were collected from each test heap in the beginning and in the end of the test period (see figure 7). Wastewaters were collected and analysed in the beginning, during and end of each test period (see figure 8).

Figure 7. Composting material was analysed from each test heap in the beginning and in the end of each test period.

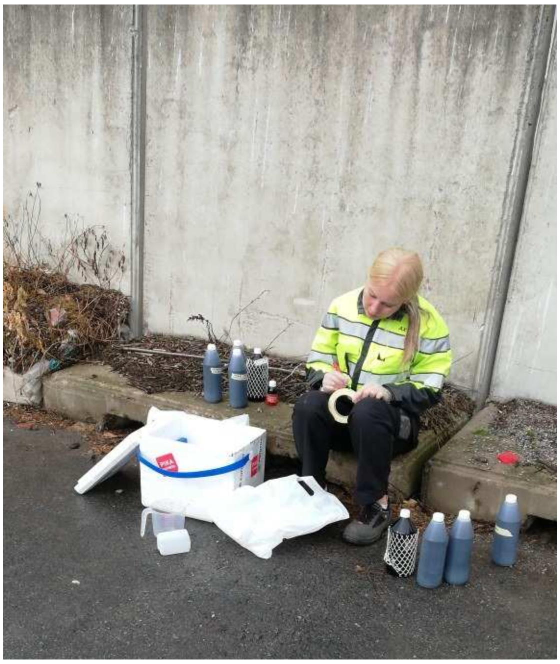

Figure 8. Waste water samples.

Final measurements and sampling procedure of the composting tests were made in the beginning of June 2020. Test heaps were composted about 5-6 months and the harmful organic substances were well degraded. After the composting period the post-maturing time of about 6 months is needed so that the composting material will be mature. This will be determined e.g. by CO_2 measurements, phytotoxicity analyses and NO_3-N / NH_4-N ratio.

The standard for the soil improvers and growing media and sampling procedure is according to the SFS-EN 12579.

5 National regulations and limit values for composting material

Following regulations and limit values of waste foundry sand must be fulfilled in order to re-use foundry sand in ground construction or gardening purposes in Finland:

1) The Finnish regulations of waste foundry sand as according to the *Government Decree of landfills (331/2013)*: Foundry sand must fulfill the limit values set for the non-hazardous inert waste. “Waste material may not endanger surface or ground water quality and may not react or no harmful substances can dissolve from it.”

   Before reusing foundry sand, the environmental permit must be always applied in Finland. This will take months or even years and the procedure is considered very time consuming.

   Table 1. The Finnish regulations of non-hazardous inert waste as according to the Government Decree of landfills (331/2013).

Taulukko 2

Aine/muuttuja	Raja-arvo, mg/kg kuiva-ainetta (L/S = 10 l/kg)
Arseeni (As)	0,5
Barium (Ba)	20
Kadmium (Cd)	0,04
Kromi yhteensä (Cr_{kok})	0,5
Kupari (Cu)	2
Elohopea (Hg)	0,01
Molybdeeni (Mo)	0,5
Nikkeli (Ni)	0,4
Lyijy (Pb)	0,5
Antimoni (Sb)	0,06
Seleeni (Se)	0,1
Sinkki (Zn)	4
Kloridi (Cl^-)	800
Fluoridi (F^-)	10
Sulfaatti (SO_4^{2-})	1 000 [1)]
Fenoli-indeksi	1
Liuennut orgaaninen hiili (DOC) [2)]	500
Liuenneiden aineiden kokonaismäärä (TDS) [3)]	4 000

[1)] Jätteen katsotaan täyttävän kelpoisuusvaatimuksen myös, jos sulfaattipitoisuus ei ylitä seuraavia arvoja: 1 500 mg/l (läpivirtaustestin ensimmäinen uutos uuttosuhteessa L/S = 0,1 l/kg) ja 6 000 mg/kg (uuttosuhteessa L/S = 10 l/kg): pitoisuuden määrittämiseksi uuttosuhteessa L/S = 0,1 l/kg on käytettävä läpivirtaustestiä: pitoisuus uuttosuhteessa L/S = 10 l/kg voidaan määrittää joko ravistelu- tai läpivirtaustestillä.

[2)] Jos liuenneen orgaanisen hiilen raja-arvo ylittyy jätteen omassa pH:ssa, voidaan jäte vaihtoehtoisesti testata uuttosuhteessa L/S = 10 l/kg pH:ssa 7,5–8,0; jätteen katsotaan täyttävän liuenneen orgaanisen hiilen kelpoisuusvaatimuksen, jos pitoisuus on enintään 500 mg/kg.

[3)] Liuenneiden aineiden kokonaismäärän raja-arvoa voidaan soveltaa sulfaatin ja kloridin raja-arvojen sijasta.

Taulukko 3

Aine/muuttuja	Raja-arvo, mg/kg kuiva-ainetta
Orgaanisen hiilen kokonaismäärä (TOC)	30 000 (3 %)
Bentseeni, tolueeni, etyylibentseeni ja ksyleenit (BTEX)	6
Polyklooratut bifenyylit (PCB) [1)]	1
Mineraaliöljy (C10–C40)	500
Polyaromaattiset hiilivedyt (PAH) [2)]	40

[1)] Kongeneerien 28, 52, 101, 118, 138, 153 ja 180 kokonaismäärä.

[2)] Yhdisteiden (antraseeni, asenafteeni, asenaftyleeni, bentso(a)antraseeni, bentso(a)pyreeni, kryseeni, bentso(b)fluoranteeni, bentso(g,h,i)peryleeni, bentso(k)fluoranteeni, dibentso(a,h)antraseeni, fenantreeni, fluoranteeni, fluoreeni, indeno(1,2,3-cd)pyreeni, naftaleeni, pyreeni) kokonaismäärä.

2) The revised *Government Decree (843/2017 MARA-asetus)* of the recovery of certain wastes in earth construction has listed foundry

waste sand as one of the raw materials to be reused for geoconstruction purposes. Nevertheless some limit values are as strict as the non-hazardous inert waste limit values (331/2013). Therefore only few foundries can benefit of this MARA decree in the future and majority of foundries must find alternative cleaning methods or reuse applications for their waste sands.

Following regulation and limit values of the composting end-product must be fulfilled in order to use the new end-product as the growing media ("Mixture soil").

3) *Regulations and limit values set for the composted end-product* are set in *the Decree of the Ministry of Agriculture and Forestry on Fertiliser Products (24/2011): Substrate – Mixture soil (5A2).* This regulation sets limit values and demands for heavy metals of the end-product, pathogens (Salmonella and *E. coli*) and impurities (weeds, garbage). Also there is a following demand in this regulation:

"In case mineral soil from metallurgical industry is used as raw material for mixture soil, such as **waste foundry sand**, it must meet the criteria of **harmful metals and organic harmful substances for positioning to the inert solid landfills"**.

Tables 2 and 3. Limit values for the end-product to be fulfilled (24/11).

LIITE IV

LANNOITEVALMISTEIDEN HAITALLISET AINEET, ELIÖT JA EPÄPUHTAUDET

Tässä liitteessä esitettävät vaatimukset haitallisista aineista, eliöistä ja epäpuhtauksista sekä kasviperäisten raaka-aineiden käsittelystä koskevat kaikkia lannoitevalmisteita, ellei muuta ole mainittu. Nämä raja-arvot eivät koske kaatopaikkojen tai muiden suljettujen alueiden, kuten suljettujen teollisuusalueiden ja lentokenttien, maisemoinnissa käytettäviä maanparannusaineita, kasvualustoja tai muita lannoitevalmisteita eikä sellaisina käytettäviä sivutuotteita.

A. HAITALLISET AINEET

Haitalliset metallit ja niiden enimmäispitoisuudet on ilmoitettu taulukossa 1. Tuoteselosteessa tulee pitoisuudet ilmoittaa Eviran kansallisten lannoitevalmisteiden tyyppinimiluettelossa mainittujen tuotteiden osalta taulukon järjestyksessä, todettuna enimmäispitoisuutena esim. "Arseeni (As) enintään xx mg/kg".

Taulukko 1. Haitallisten metallien enimmäispitoisuudet epäorgaanisissa lannoitteissa ja kalkitusaineissa typpihapolla uutettuna sekä muissa lannoitevalmisteissa kuningasvesimärkäpolttomenetelmällä uutettuna.

Alkuaine	Enimmäispitoisuus mg/kg kuiva-ainetta	Metsätaloudessa käytettävissä tuhkalannoitteissa tai niiden raaka-aineena käytettävässä tuhkassa enimmäispitoisuus mg/kg ka.
Arseeni (As)	25	40
Elohopea (Hg)[1)]	1,0	1,0
Kadmium (Cd)	1,5 [2)]	25
Kromi (Cr)	300 [3)]	300
Kupari (Cu)	600[4)]	700
Lyijy (Pb)	100	150
Nikkeli (Ni)	100	150
Sinkki (Zn)	1500[4)]	4500[4)]

[1)] Elohopean määritys EPA 743-menetelmällä

[2)] 2,5 mg Cd/kg ka maa- ja puutarhataloudessa sekä viherrakentamisessa ja maisemoinnissa käytettävässä tuhkalannoitteissa tai niiden raaka-aineena käytettävässä tuhkassa

[3)] Sellaisenaan kalkitusaineena käytettävälle sivutuotteelle teräskuona (tyyppinimi 2A2/3) määritetään kromi liukoisena kuuden arvoisena kromina (Cr 6+). Raja-arvo liukoiselle kuuden arvoiselle kromille on 2,0 mg/kg kuiva-ainetta.

[4)] Enimmäispitoisuuden ylitys lannoitevalmisteissa voidaan sallia, kun maaperäanalyysin perusteella on todettu puutetta kuparista tai sinkistä. Metsätaloudessa enimmäispitoisuuden ylitys lannoitevalmisteena käytettävässä sivutuotteessa on sallittu ainoastaan sinkkiä suometsissä käytettäessä, silloin kun sinkin puute on kasvustosta todettu joko maaperä-, lehti- tai neulasanalyysillä Tällöin maksimimäärä sinkkiä lannoitevalmisteena käytettävässä sivutuotteessa saa olla enintään 6000 mg Zn/kg ka.

B. TAUDINAIHEUTTAJAT JA MUUT MIKRO-ORGANISMIT

Tautia aiheuttavien tai niitä indikoivien mikro-organismien sallitut enimmäismäärät on esitetty taulukoissa 2 ja 3.

Taulukko 2. Lannoitevalmisteissa sallitut taudinaiheuttajien/indikaattorieliöiden enimmäismäärät.

Taudinaiheuttaja/indikaattori	Enimmäismäärä
Salmonella	Ei todettavissa 25 grammassa näytettä
Escherichia coli	1000 pmy/g ja alle 100 pmy/g ammattimaiseen kasvihuoneviljelyyn tarkoitetuissa kasvualustoissa, joissa syötävät kasvinosat ovat suoraan kosketuksissa kasvualustaan
Juuripoltesieni (mm. *Fusarium;* todettu viljelytestillä)	Ei todettavissa taimituotannossa käytetyissä kasvualustoissa

Taulukko 3. Kasviperäisistä raaka-aineista tai niiden mukana tulevista multajakeista valmistettujen lannoitevalmisteiden erityisvaatimukset.

Kasvintuhooja	Enimmäismäärä
Keltaperuna-ankeroinen (*Globodera rostochiensis)* Valkoperuna-ankeroinen (*Globodera pallida)* Perunan vaalea rengasmätä (*Clavibacter michicanensis)* Perunan tumma rengasmätä (*Ralstonia solanacearum)* Perunasyöpä *(Synchytrium endobioticum)* Juurikkaan nekroottinen keltasuonivirus (Beet necrotic yellow vein virus) "Ritsomania" Juuriäkämäankeroinen (*Meloidogyne* spp.*)*	Ei todettavissa juures-, juurikas- ja perunaraaka-aineesta tai näiden mukana tehtaalle tai kuorimoon tulevista multajakeista valmistetussa lannoitevalmisteessa.
Muut kasvitauteja aiheuttavat karanteenituhoojat	Ei todettavissa kasvihuonetuotannon kasvijätteestä tai kasvualustoista valmistetuissa lannoitevalmisteissa.

The Fertilisers Product decree was renewed on 5th July 2019: "*The EU Degree on Fertiliser Product (2019/1009)*" including now new limit values and regulations e.g. for compost products and digestate-based organic fertilisers. The national law of Finland is planned to enter into effect after the year of 2022. Until then, the existing limit values of Decree of 24/11 are followed. However, the new limit values and regulations (2019/1009) are taken into account for the future products which are demonstrated in this project.

6 Results of the composting tests with organic binder system waste sand and dust in 2019-2020

Analyses were made from different composting fractions:
1) waste foundry sand and dust specimens before the composting tests,
2) mixed composting materials and
3) wastewaters from the pilot site.

Composting materials were analysed in the beginning and end of each test period. Wastewater samples were collected in the beginning, middle and end of each test period.

The “pure” foundry sand used in all organic and inorganic binder systems tests is silica sand (quartz sand).

The relevant results are reported in following paragraphs below.

6.1 pH

Composting progress can be followed by measuring nitrogen compounds and pH changes. In the beginning of the composting pH can reduce but it will rise again during the maturation of compost (VTT 2006).

There is no limit value for pH for non-hazardous inert waste.

pH of foundry dust was 8,0 and foundry waste sand 7,5. pH of composting heaps was similar (6,6-6,7) in the beginning and in the end of the composting test.

6.2 Total and dissolved organic carbon (TOC and DOC)

Dissolved organic carbon (DOC) concentration of dust (4500 mg/kg dm) and waste sand (1600 mg/kg dm) exceeded the limit value for non-hazardous inert waste that is 500 mg/kg dm. Total organic carbon concentrations were below the limit value (3 % dm). The results are presented in table 4.

For composting end-product (Decree of 24/11) there is no limit value for DOC or TOC.

6.3 Fluoride

Fluoride concentrations of test samples are presented in figure 9. Fluoride concentration was particularly high in dust (180 mg/kg dm). Also in waste sand the fluoride concentration (23 mg/kg dm) was above the 10 mg/kg dm limit value of non-hazardous inert waste. The fluoride is most probably coming from the fluoride containing feeders used in the molds used in all sand systems. It is expected that less foundries use the fluoride containing feeders in the future. Substitute materials are available in the market already.

During the test the fluoride concentration of dust compost heap reduced but remained slightly above the limit value. Fluoride concentration of waste sand compost heap was below the limit value already in the beginning of the test.

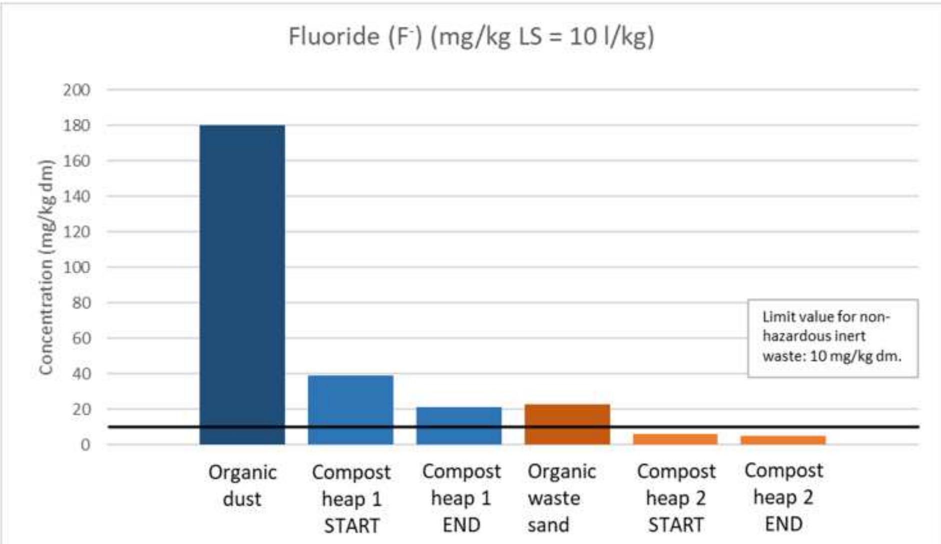

Figure 9. Fluoride concentrations of organic dust and organic waste sand and the composting heaps during the test.

6.4 Chloride and sulphate

Chloride and sulphate concentrations of dust (67 mg/kg dm and 420 mg/kg dm) and waste sand (<10 mg/kg dm and 84 mg/kg dm) were below the limit values for non-hazardous inert waste that are for chloride 800 mg/kg dm and for sulphate 1000 mg/kg dm. In the beginning of one compost test chloride concentration was 1300 mg/kg dm. Chloride origins from animal manure used in composting process. Chloride salt is used in animal feed. There are no limit values for chloride according to decree 24/11 for mixture soil material. The results are presented in table 4.

6.5 Phenols

Phenol concentrations of test samples are presented in figure 10. Phenol concentrations (Phenol Index) of dust (1,2 mg/kg dm) and waste sand (2,1 kg/mg dm) were slightly above the 1 mg/kg dm limit value of non-hazardous inert waste.

In the beginning of the compost tests, phenol concentrations of compost heaps were above the limit value in both heaps but the concentrations reduced during the tests and in the end the concentrations were below the limit value.

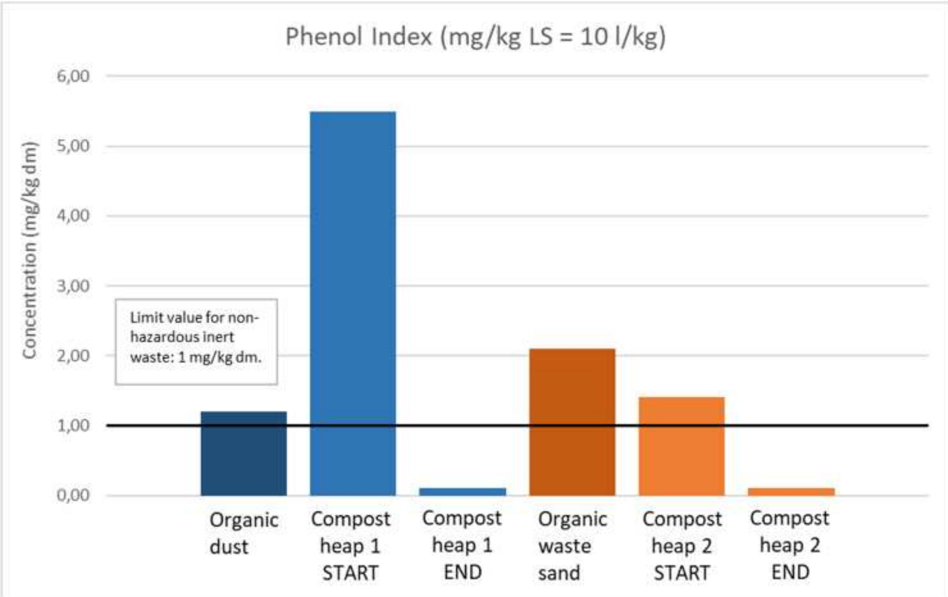

Figure 10. Phenol concentrations of dust and waste sand and during the composting tests.

6.6 Other harmful organic compounds

Also other organic compounds that were analysed – BTEX compounds, PAH compounds, PCB compounds and hydrocarbons C10-C40 – concentrations were under limit values set in the Decree of the Ministry of Agriculture and Forestry on Fertiliser Products 24/11 and Government Decree of landfills 331/2013 (limit values for inert solid waste). The results are presented in table 4.

Table 4. Organic compounds in organic dust, organic waste sand and composting heaps. Limit values for inert waste and compost end-product (current and future values) are listed in the table. The value that exceeds the limit value is marked with yellow colour.

Analysis	Unit	Organic dust	Compost heap 1 START	Compost heap 1 END	Organic waste sand	Compost heap 2 START	Compost heap 2 END	Limit value for non-hazardous inert waste	Limit value for compost product (current)	Limit value for compost product (future)
BTEX	mg/kg dm	0,99	n.c.	n.c.	0,17	n.c.	n.c.	6	-	-
16 EPA-PAH	mg/kg dm	2,06	1,55	0,13	0,45	0,51	n.c.	40	-	6
Chloride (mg/kg LS = 10 l/kg)	mg/kg dm	67	1300	640	<10	490	330	800	-	-
Sulphate (mg/kg LS = 10 l/kg)	mg/kg dm	420	130	98	84	49	57	1000	-	-
PCB-7	mg/kg dm	n.c.	n.c.	n.c.	n.c.	n.c.	n.c.	1	-	-
Hydrocarbons C10>C40	mg/kg dm	92	140	<40	<40	80	<40	500	-	-
Total organic carbon (TOC)	% dm	2,4	12	12	0,7	-	9,4	3	-	-
Dissolved organic carbon (DOC)	mg/kg dm	4500	7800	2100	1600	4700	1700	500	-	-

- = Not analyzed from the sample, or concerning a limit value; there is no limit value for the parameter.

n.c. = Not calculated; the result is formed from a sum of many compunds that were analysed below the detection limit.

6.7 Dissolved metals and total concentrations of metals

The concentrations of dissolved molybdene (1,08 mg/kg dm) in dust were above the limit values of non-hazardous inert waste (see figure 11). However, the concentration was below the limit values already in the beginning of the test.

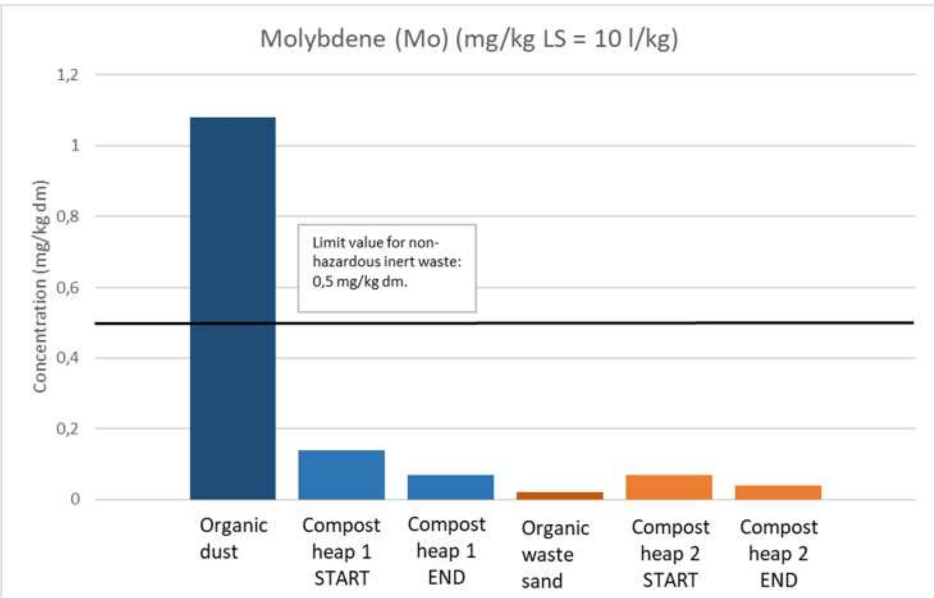

Figure 11. Molybdene (Mo) concentrations of organic dust and organic waste sand and the composting heaps during the test.

The concentrations of other dissolved metals and total concentrations of all metals in dust and waste sand and composting test heaps were under limit values for inert solid waste (331/2013) and the Decree of the Ministry of Agriculture and Forestry on Fertiliser Products 24/11 and the EU Degree on Fertiliser Product (2019/1009). These results are presented in table 5.

Table 5. Water soluble metals and total metals in organic dust, organic waste sand and composting heaps. Limit values for inert waste and compost product (current and future values) are listed in the table. The value that exceeds the limit value is marked with yellow colour.

Analysis	Unit	Organic dust	Compost heap 1 START	Compost heap 1 END	Organic waste sand	Compost heap 2 START	Compost heap 2 END	Limit value for non-hazardous inert waste	Limit value for compost product (current)	Limit value for compost product (future)
Soluble in water (two-Step L/S=10 leachate)										
Antimony (Sb)	mg/kg dm	0,08	<0,01	<0,01	<0,01	<0,01	<0,01	0,06	-	-
Arsenic (As)	mg/kg dm	0,06	0,07	0,09	0,05	0,08	0,06	0,5	-	-
Barium (Ba)	mg/kg dm	0,14	0,42	0,71	0,03	0,54	0,47	20	-	-
Cadmium (Cd)	mg/kg dm	<0,003	<0,003	<0,003	<0,003	0,004	<0,003	0,04	-	-
Chromium (Cr)	mg/kg dm	0,11	0,07	0,01	0,03	0,04	0,02	0,5	-	-
Copper (Cu)	mg/kg dm	1,4	0,53	0,72	0,11	0,85	0,75	2	-	-
Lead (Pb)	mg/kg dm	0,11	0,38	0,07	0,02	0,38	0,07	0,5	-	-
Molybdenum (Mo)	mg/kg dm	1,08	0,14	0,07	0,02	0,07	0,04	0,5	-	-
Nickel (Ni)	mg/kg dm	0,13	0,28	0,11	0,01	0,15	0,05	0,4	-	-
Selenium (Se)	mg/kg dm	0,05	<0,01	0,01	<0,01	<0,01	<0,01	0,1	-	-
Zinc (Zn)	mg/kg dm	0,9	1,0	2,3	<0,1	1,9	2,9	4	-	-
Mercury (Hg)	mg/kg dm	<0,002	<0,002	<0,002	<0,002	<0,002	<0,002	0,01	-	-
Total amount (aqua regia digestion)										
Antimony (Sb)	mg/kg dm	<1	<1	<1	<1	<1	<1	-	-	-
Arsenic (As)	mg/kg dm	1,4	1,0	1,3	<0,8	2,6	<0,8	-	25	40
Barium (Ba)	mg/kg dm	47	45	60	9	11	32	-	-	-
Cadmium (Cd)	mg/kg dm	<0,2	<0,2	<0,2	<0,2	<0,2	<0,2	-	1,5	1,5
Chromium (Cr)	mg/kg dm	43	19	25	13	3	13	-	300	-
Copper (Cu)	mg/kg dm	146	59	78	11	2	25	-	600	200
Lead (Pb)	mg/kg dm	15	9	27	2	3	4	-	100	120
Molybdenum (Mo)	mg/kg dm	5	-	2	<2	-	<2	-	-	-
Nickel (Ni)	mg/kg dm	25	9	12	3	3	8	-	100	50
Selenium (Se)	mg/kg dm	<1	<1	<1	<1	<1	<1	-	-	-
Zinc (Zn)	mg/kg dm	112	75	98	14	10	44	-	1500	500
Mercury (Hg)	mg/kg dm	<0,07	<0,07	<0,07	<0,07	<0,07	<0,07	-	1	1
Chromium (Cr) VI	mg/kg dm	-	-	-	-	-	-	-	-	2

- = Not analysed from the sample. When concerning a limit value, means that there is no limit value for the parameter.

6.8 Maturity of compost materials

The compost maturity can be tested with different kind of tests. Very common tests to study the compost material are germination test and root length index, that tell how plants can grow in the compost material and if it is too toxic for plant growth. Carbon dioxide productivity tell about the microbial activity of the compost materia – if there is lots of compounds that can be degraded, microbial activity is high and so is the carbon dioxide production.

NO_3-N / NH_4-N ratio describes the maturity of the compost because the state of nitrogen changes in the composting process. In raw compost material nitrogen is mainly in state of ammonium or ammonia. During maturing the portion of nitrate and nitrite grows. In mature compost material the NO_3-N / NH_4-N ratio should be over 1.

Pathogen tests demonstrate how well the materia is composted and hygienised.

The maturity of the composting materials was tested in the end of the composting tests. Following parameters were analysed to estimate the maturity: germination (%), root length index (%), carbon dioxide production, NO_3-N/ NH_4-N-ratio and pathogens (*E. coli*, *Salmonella*).

Germination test gave good results for the end situation samples of compost heap 1 and 2 (Table 6). Anyhow, the root length index showed that the limit value of 80 % was not fulfilled. In organic dust compost the root length index value could be interpreted to be at the limit value. However, in organic waste sand compost the root length index value was clearly below the limit value. This tells that the plant seeds germinated very well, but the plants could not yet grow well in the waste sand compost sample.

The carbon dioxide production results for the end situation samples of dust compost and waste sand compost indicate, that the carbon dioxide production was not detected.

The NO_3-N / NH_4-N ratio describes mature compost material in both compost heaps.

E. coli colony forming unit value of dust compost was below the detection limit (10 cfu/g). In waste sand compost the colony forming unit value was very low and well below the limit value. Salmonella was not detected in compost heaps.

Table 6. Compost maturity results of the organic dust (Compost heap 1) and organic waste sand (Compost heap 2) composting heaps. Limit values for compost product are listed in the table. The value that exceeds the limit value is marked with yellow colour.

Analysis	Unit	Compost heap 1 END	Compost heap 2 END	Limit value of Fertiliser Product Decree 24/11
Germination test	%	96	96	>80
Root lenght index	%	79	58	>80
Carbon dioxide production	mg C/g volatile solids	<0,2	<0,2	<3
NO_3-N/NH_4-N-ratio		48	33	>1
E. coli	cfu/g	<10	20	<1000
Salmonella	/ 25 g	Not detected.	Not detected.	Must not be detected.

Compost materials were post-matured until 18.11.2020 at the site and the end-product was mature and clean and was reused at the Tarastenjärvi landfill site for green construction purposes.

6.9 Wastewaters from composting tests

The quality of waste waters of composting area was observed. Wastewater samples were taken in the beginning, middle and end of the composting tests. The wastewater results are presented in table 7.

Only value that exceeded the wastewater limit values in summer 2019 composting tests was phenol concentration in the beginning of the composting test (17 mg/l). But the exceeding was very minor.

The end situation wastewater sample of the summer 2019 composting test was at the same time start situation sample for the summer 2020 composting test (composting heap 3) because the previous tests were completed on the same time as the new composting test, heap 3, was started. This explains why the concentrations are so high compared to the middle situation concentrations.

Only value that exceeded the wastewater limit values in summer 2020 composting tests was solid matter concentration in the end of the composting test (620 mg/l). This was due to the small amount of wastewaters in sampling dam when collecting the final samples. The limit value of solid matter in wastewater is 500 mg/l. The exceeding was considered minor.

Table 7. Results of the wastewater analyses of the samples taken from the composting site.

		Summer test 2019		Summer test 2020			
Analysis	**Unit**	**Start 14.8.2019**	**Middle 13.11.2019**	**End / Start 1.7.2020**	**Middle 17.9.2020**	**End 19.11.2020**	**Limit value**
Aluminium (Al)	mg/l	0,27	0,20	5,3	2,2	7,1	-
Arsenic (As)	mg/l	-	-	0,0080	<0,005	0,0082	0,1
Mercury (Hg)	mg/l	<0,0001	<0,0001	0,00018	<0,0001	0,00011	0,01
Cadmium (Cd)	mg/l	0,0015	0,00022	0,0011	0,00091	0,0015	0,01
Chromium (Cr)	mg/l	<0,003	0,0047	0,023	0,011	0,034	1
Copper (Cu)	mg/l	0,091	0,024	0,11	0,092	0,15	2
Lead (Pb)	mg/l	0,015	0,0018	0,032	0,019	0,056	0,5
Nickel (Ni)	mg/l	0,012	0,0051	0,025	0,014	0,026	0,5
Iron (Fe)	mg/l	1,4	0,36	10	4,7	13	-
Zinc (Zn)	mg/l	0,19	0,037	0,27	0,22	0,41	3
Total Nitrogen TNb	mg/l	28	6,8	16	9,3	28	-
Ammonium	mg/l	5,6	<2,0	3,7	0,14	5,3	-
Total phosphorus	mg/l	15	4,9	10	4,5	10	-
Chloride (Cl^-)	mg/l	-	12	36	14	49	-
Sulphate (SO_4^{2-})	mg/l	12	2,1	7,9	4	7,3	400
Fluoride (F^-)	mg/l	0,31	<0,1	0,16	0,18	0,26	-
pH	mg/l	7,1	7,5	7,0	7,9	7,1	6,0-11,0
BOD7	mg/l	30	2,6	37	9,5	57	-
CODcr	mg/l	940	230	580	480	1000	-
Solid Matter	mg/l	-	9,8	390	120	620	500
Fecal coliforms (bacteria)	cfu/100 ml	-	-	>1000000	3800	150	-
Electrical Conductivity	µS/cm	780	180	350	200	490	-
Phenol Index	mg/l	17	2,2	3,1	<0,008	<0,050	10
Polycyclic Aromatic Hydrocarbons (PAH)	mg/l	0,0001	0,0001	0,00016	0,00009	0,00014	0,05
BTEX	mg/l	0,0002	n.c.	n.c.	n.c.	n.c.	3
Hydrocarbons C10-C40	mg/l	-	<0,02	0,10	0,17	0,11	100

- = no limit value for the parameter n.c. = incalculable, because all the concentrations were below detection limits.

The limit values are from the Ekokem Instruction 1/09 (Ekokemin ohje 1/09) "Älä päästä haitallista ainetta viemäriin" and the waste water limit value list of Tampere Water (2016).

7 Composting tests in 2020

In summer-autumn 2020 one composting test heap of *inorganic binder system waste sand* was constructed. Inorganic binder system waste sand was transported from Karhula Foundry from the test casts.

The size of this test heap was 11 tons where inorganic binder system waste sand portion was 16%. Other organic materials like wood chips and animal manure were used. This composting test period was 5 months.

Figure 12. Constructing the composting test heap with inorganic binder system waste sand in June 2020.

Figure 13. All three composting test heaps at Tarastenjärvi site.

8 Results of the composting test with inorganic binder system waste sand in 2020

The progress of the composting process was controlled by measuring temperature continuously.

Temperature raised rapidly to 70 degrees after starting the composting test (figure 14). The temperature was well above 55 degrees for over 2 months from June – August. According to the decree of 24/11 the temperature should stay over 55 degrees for 14 days. The results demonstrate efficient composting method.

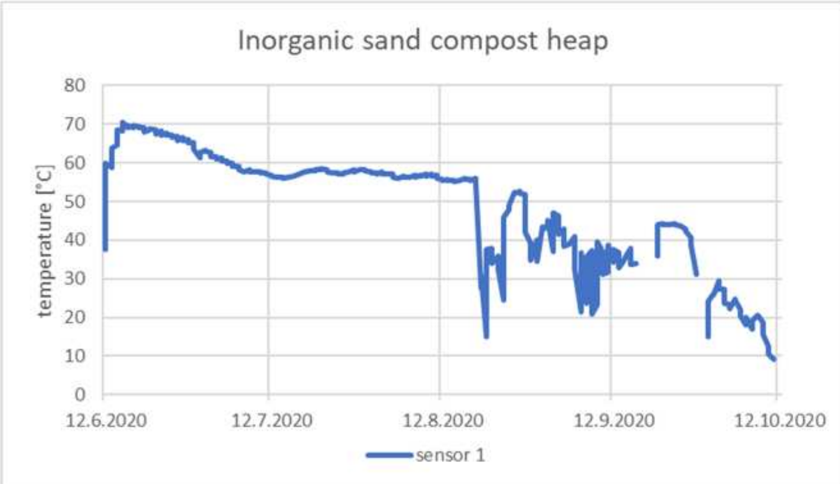

Figure 14. Temperature changes in compost test heap with inorganic foundry sand in depth of 1,5 m in June-October 2020.

Inorganic waste sand was analysed before the composting tests. Analyses were also taken in the beginning and end of the composting tests and wastewater were collected in the beginning, middle and end of the test period.

The inorganic foundry sand was very clean already before the composting treatment. The waste sand did not contain any harmful compounds or metals. The results of the inorganic binder system foundry sand and legislative limit values are presented in table 8.

Based on the analyses results the inorganic binder system foundry sand could be re-used without any additional cleaning method e.g. in geo-engineering purposes as it fulfills the requirements of the Government Decree on the Recovery of Certain Wastes in Earth Construction 843/2017. It could also be mixed with other compost materials in the beginning or end of the composting process instead of virgin soil material that is needed in the compost end-product (mixture soil material).
Results of the wastewater analyses are presented in table 7 (see Chapter 6.9 Waste waters from composting tests).

Table 8. The analysis results of the inorganic binder foundry sand.

Analysis	Unit	Inorganic bounder system foundry sand (Compost heap 3)	GD on Landfills 331/2013, inert waste limit value	GD on the recovery of certain wastes in earth construction 843/2017 (limit value range)	Decree on Fertiliser Products 24/11 limit values	New Decree on Fertiliser Products EU 2019/1009 limit values for substrateand compost (in force in July 2022 forward)
Dry matter	weight-%	99,5	-	-	-	-
pH (CaCl2)		9,8	-	-	-	-
Total organic carbon (TOC)	% dm	0,2	3	-	-	-
Dissolved organic carbon (DOC) (mg/kg LS = 10 l/kg)	mg/kg dm	230	500	500	-	-
Phenol index mg/kg LS = 10 l/kg	**mg/kg dm**	**0,11**	**1**	**-**	**-**	**-**
Phenol	mg/kg dm	0,10	-	-	-	-
o-cresol (2-methylphenol)	mg/kg dm	<0,05	-	-	-	-
m-kresoli (3-methylphenol)	mg/kg dm	<0,05	-	-	-	-
p-kresoli (4-methylphenol)	mg/kg dm	<0,05	-	-	-	-
Bisphenol-A	mg/kg dm	<0,1	-	-	-	-
Sum concentration of Phenolic Compounds	**mg/kg dm**	**0,1**	**-**	**5-10**	**-**	**-**
Benzene	mg/kg dm	0,01	-	0,02-0,2	-	-
BTEX (sum)	**mg/kg dm**	**0,01**	**6**	**-**	**-**	**-**
TEX (sum)	mg/kg dm	n.c.	-	10-25	-	-
Naphthalene	mg/kg dm	<0,05	-	5	-	-
Sum 16 EPA-PAH	**mg/kg dm**	**n.c.**	**40**	**30**	**-**	**6**
Fluoride (mg/kg LS = 10 l/kg)	mg/kg dm	<5,0	10	10-150	-	-
Chloride (mg/kg LS = 10 l/kg)	mg/kg dm	<10	800	800-11000	-	-
Sulphate (mg/kg LS = 10 l/kg)	mg/kg dm	20	1000	1200-18000	-	-
Sum PCB-7	mg/kg dm	n.c.	1	1	-	-
Hydrocarbons C10-C40	**mg/kg dm**	**<40**	**500**	**300-500**	**-**	**-**
Water soluble metals					-	-
Antimony (Sb) mg/kg LS = 10 l/kg	mg/kg dm	0,05	0,06	0,3-0,7	-	-
Arsenic (As) mg/kg LS = 10 l/kg	mg/kg dm	0,13	0,5	0,5-2	-	-
Barium (Ba) mg/kg LS = 10 l/kg	mg/kg dm	0,05	20	20-100	-	-
Cadmium (Cd) mg/kg LS = 10 l/kg	mg/kg dm	<0,003	0,04	0,04-0,06	-	-
Chromium (Cr) mg/kg LS = 10 l/kg	mg/kg dm	0,02	0,5	0,5-10	-	-
Copper (Cu) mg/kg LS = 10 l/kg	mg/kg dm	<0,05	2	2-10	-	-
Lead (Pb) mg/kg LS = 10 l/kg	mg/kg dm	<0,01	0,5	0,5-2	-	-
Molybdenum (Mo) mg/kg LS = 10 l/kg	mg/kg dm	0,03	0,5	0,5-6	-	-
Nickel (Ni) mg/kg LS = 10 l/kg	mg/kg dm	<0,01	0,4	0,4-2	-	-
Selenium (Se) mg/kg LS = 10 l/kg	mg/kg dm	<0,01	0,1	0,4-1	-	-
Zinc (Zn) mg/kg LS = 10 l/kg	mg/kg dm	0,3	4	4-15	-	-
Mercury (Hg) mg/kg LS = 10 l/kg	mg/kg dm	<0,002	0,01	0,01-0,03	-	-
Vanadium(V) mg/kg LS = 10 l/kg	mg/kg dm	<0,1	-	2-3	-	-
Total metal concentrations (aqua regia)						
Antimony (Sb)	mg/kg dm	<1	-	-	-	-
Arsenic (As)	mg/kg dm	<0,8	-	-	25	40
Barium (Ba)	mg/kg dm	9	-	-	-	-
Cadmium (Cd)	mg/kg dm	<0,2	-	-	1,5	1,5
Chromium (Cr)	mg/kg dm	17	-	-	300	-
Copper (Cu)	mg/kg dm	13	-	-	600	200
Lead (Pb)	mg/kg dm	4	-	-	100	120
Molybdenum (Mo)	mg/kg dm	<2	-	-	-	-
Nickel (Ni)	mg/kg dm	7	-	-	100	50
Selenium (Se)	mg/kg dm	<1	-	-	-	-
Zinc (Zn)	mg/kg dm	34	-	-	1500	500
Mercury (Hg)	mg/kg dm	<0,07	-	-	1	1
Hexavalent Chromium (Cr(VI))	mg/kg dm	-	-	-	-	2

9 Conclusions of the composting tests in two test periods

In composting tests in Tarastenjärvi following sand/dust types were tested

- organic binder system (Alphaset) waste sand
- organic binder system (Alphaset) dust
- different inorganic binder system waste sands (confidential)

The “pure” foundry sand type in all cases is silica sand (quartz sand).

In summer 2019 the composting tests were carried out with **organic binder system (phenol) waste sand and dusts**. *DOC concentrations* of dust and waste sand were above the limit value of non-hazardous inert waste. *Fluoride concentration* was high in dust specimen and waste sand samples. The fluoride is probably coming from the fluoride containing feeders used in the molds used in all sand systems. It is expected that less foundries use the fluoride containing feeders in the future. Substitute materials are available in the market already. During the composting test fluoride concentrations were reduced below the limit values or close to it.

Phenol concentrations of dust and waste sand exceeded the limit value before the composting test. In addition to the sand mould system phenols can also origin from the core production when produced by cold-box system. Phenols were degraded during the composting tests, so that in the end situation the concentrations were below the limit value.

D*issolved molybdene* concentration in dust was above the limit value of non-hazardous inert waste, but the concentration in dust compost heap was below the limit value already in the beginning and end of the composting test.

Based on the results of the summer 2019-2020 composting tests, we can assume that the tests were successfully completed and the innovative *composting end-product fulfilled the limit values set in the Decree of the Ministry of Agriculture and Forestry on Fertiliser Products 24/2011 and The EU Degree on Fertiliser Product (2019/1009) and the end-product can be re-used as substrate and for gardening and geo-construction purposes.*

Degradation of the harmful substances during the composting tests demonstrate very good cleaning efficiency rates (Table 9). The composting method can be considered as an effective cleaning method.

Table 9. The degradation of the harmful substances during the composting tests and the cleaning efficiency rates.

	Organic dust	**Organic waste sand**	Limit value for non-hazardous inert waste	Compost heap 1 (organic dust) START	Compost heap 2 (organic waste sand) START	Compost heap 1 (organic dust) END	Compost heap 2 (organic waste sand) END	**Compost heap 1 (organic dust) Degradation efficiency**	**Compost heap 2 (organic waste sand) Degradation efficiency**
DOC, mg/kg dm	4500	1600	500	7800	4700	2100	1700	**73 %**	**64 %**
Phenol index, mg/kg dm	1,20	2,10	1	5,5	1,4	<0,10	<0,10	**98 %**	**93 %**
Fluoride, mg/kg dm	180	23	10	39	6	21	<5,0	**46 %**	**17 %**

In summer 2020 composting test were carried out with **inorganic binder system foundry waste sand.** Based on the analyses results this analysed inorganic binder system waste sand type was very clean already without the composting treatment. The “waste” sand did not contain any organic or inorganic harmful compounds or metals.

Based on the analyses results the inorganic binder system foundry sand could be re-used without any additional cleaning method e.g. in geo-engineering purposes as it fulfills the requirements of the Government Decree on the Recovery of Certain Wastes in Earth Construction 843/2017. It could also be mixed with other compost materials in the beginning or end of the composting process instead of virgin soil material that is needed in the compost end-product (mixture soil material).

10 Analyses results of the organic and inorganic binder system waste sands

In Tarastenjärvi landfill site we tested organic binder system (phenolic Alphaset) waste sand and dust and inorganic binder system waste sand received from test casts carried out at Karhula Foundry, Finland.

The “pure” foundry sand is in all cases silica sand (quartz sand).
All the tested sand and dust specimens were analysed and compared with the limit values of non-hazardous inert waste (331/2013).

The results of the inorganic and organic binder system waste sand and dust specimens are presented in table 10. Organic sand “Sample D” represents organic binder system “Alphaset” phenolic waste sand type and “Sample E” is the same sand type dust specimen. Inorganic binder system samples are from different suppliers (confidential information) which were tested in Karhula Foundry test casts in 2019-2020.

Table 10. Results of the inorganic and organic binder system waste sand and dust specimens tested in the project.

		INORGANIC SANDS						ORGANIC SANDS		
		Sample A1	**Sample A2**	**Sample A3**	**Sample B1**	**Sample B2**	**Sample C**	**Sample D**	**Sample E**	**Limit value for non-hazardous inert waste**
Dissolved organic carbon (DOC)	mg/kg dm	90	37	230	**640**	**680**	**610**	**1600**	**4500**	**500**
Phenol index	mg/kg dm	<0,1	<0,1	0,11	<0,10	<0,10	<0,10	**2,10**	**1,20**	**1**
Fluoride	mg/kg dm	<5	5,5	<5,0	<5,0	**41**	**32**	**23**	**180**	**10**
Molybdenum (Mo) (mg/kg LS = 10 l/kg)	mg/kg dm	0,04	0,02	0,03	0,03	<0,01	<0,01	0,02	**1,08**	**0,5**

In the table 10 only those compounds which exceeded the limit value set for the non-hazardous inert waste (331/2013) are presented.

DOC, phenol, fluoride and molybdenum concentrations of the *organic binder system waste sand and dust* (phenolic type) exceeded the inert waste limit values. Highest DOC concentration was detected in phenolic dust specimen.

Some *inorganic binder system* waste sand samples exceeded the *DOC and fluoride* concentrations of inert waste limit values. Based on the information received the inorganic binders themselves are free of organic substances but some suppliers may use small amount of organic substances in the hardener. Therefore, higher DOC concentrations were detected among some inorganic binder system waste sands. Fluoride origin most likely from the feeder systems used in the foundry.

Some of the tested inorganic binder systems fulfilled both the limit values of non-hazardous inert waste as according to the Government Decree of landfills (331/2013) and the Government Decree on the **Recovery of Certain Wastes in Earth Construction** 843/2017 (some reuse categories). These inorganic binder system waste sands could be re-used without any additional cleaning method e.g. in geo-engineering and road construction purposes. It could also be mixed with other compost materials in the beginning or end of the composting process instead of using virgin soil material that is needed as part of the compost material.

Based on project composting test results, the existing harmful substances of the organic binder system waste sands/dusts will be effectively degraded by composting method. This can be recommended as efficient cleaning method for foundry waste sands and the purified waste sand and compost material can be re-used as mixture soil material in gardening, green construction or noise embankment purposes.

11 References

Decree of the Ministry of Agriculture and Forestry on Fertiliser Products (24/2011): Substrate – Mixture soil (5A2).

The EU Degree on Fertiliser Product (2019/1009).

Government Decree of landfills (331/2013).

Government Decree on the Recovery of Certain Wastes in Earth Construction 843/2017.

SFS-EN 12579 Soil improvers and growing media. sampling.

VTT 2006: Kompostin kypsyystestit – Menetelmäohjeet. VTT Tiedotteita 2351. (in English: Compost Maturity Tests – Method Instructions.)