Technical report 31.12.2014
Internal

Online x-ray measurement of bio fuels. Study at UPM Kaipola power plant, Jämsä, Finland.

Inray Oy
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1. General

InrayFuel x-ray measurement system was installed to the UPM Kaipola's powerplant (Jämsä Finland) on November 2013. Purpose of x-ray measurements was collecting of deeper information about bio fuels, especially crushed stumps, and make this continuously instead of batch sampling.

Installation work took about three working days and it was done during plant's normal operation. Device container was lifted close to crusher building and x-ray scanner was installed outside of building to the fuel conveyor. The scanner doesn't have own base because vibrations of belt conveyor were estimated to be meaningless. All main electrical components like power units, generator, computer cabin, air conditions etc. were placed in the device container.

Picture 1. Inray Fuel at UPM Kaipola power plant at the end of beginning of the fuel conveyor

<u>Belt conveyor</u>
Manufactured by NN. Main dimensions:
- Width 1000mm (Fuel appr. 600mm)
- Fuel thickness varies normally between 100...250mm

Conveyor is rotating at constant speed 1.0m/s.

Picture 2. Left:Belt conveyor. Right: Detector's housing box between belts

1.1. Safety arrangements and radiation measurements

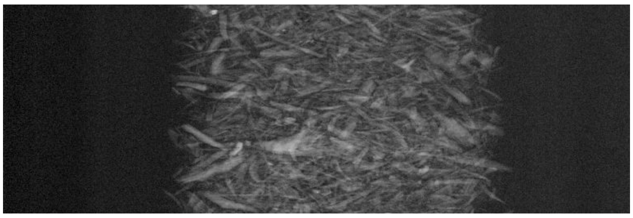
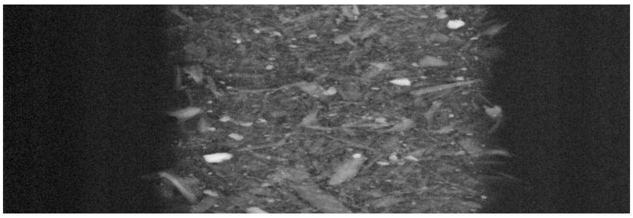
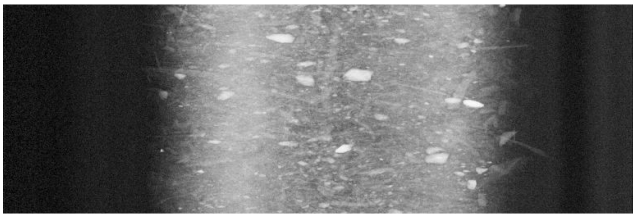
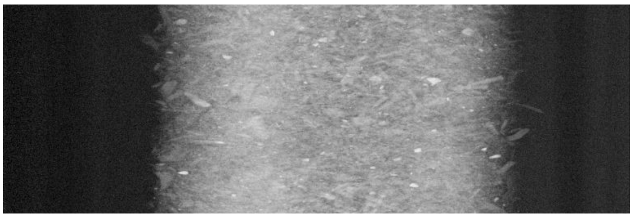
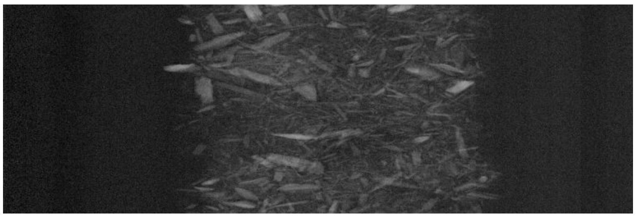
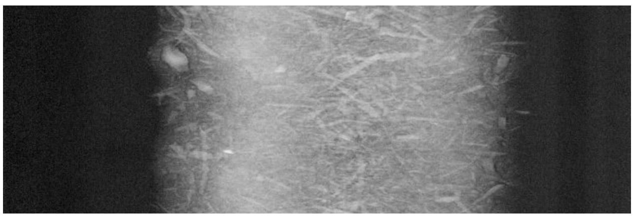
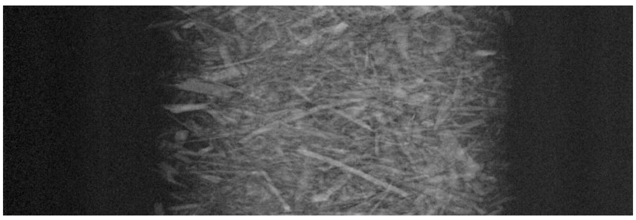
For installation and measurement period separate safety plan was made (Inray Oy). Finnish radiation safety authority STUK made inspection to safety plan, instructions and on site during November 2013. Walkways near x-ray scanner were protected with two safety gates, warning signs and warning lamps. Area close to x-ray were separated with building fences to make sure that no outsiders can enter the area during x-ray operation. All UPM workers of power plant took part to safety training and subcontractors were informed about measurements and basic safety issues. Also UPM project people were trained before measurement periods.

Radiation levels during operation were finally very small due to small needed radiation energy. Building fences were placed according to radiation measurements at maximum power of device but final driving settings of x-ray were half of maximum.

2. Measurements

2.1 General

X-ray detector scan setting was 400 stripes per second. Conveyor speed was 1m/s which means that every pixel is 2.5mm long in vertical direction. Due to installation geometry all horizontal pixels are approximately 1.3mm wide. Due to high scanning frequency data saving was manually organized so that not all raw pictures were saved. So-called histogram data exists from every single raw picture. For reporting purposes results are calculated mainly for one minute and for one batch (truck) but basic raw data exists at every picture level.

 Crushed stump chips, clean	 Forest residue, dry (3.1.2014)
 Crushed stump chips with stones	 Forest residues with ice and snow
 Crushed stump chips with soil (3.12 first mix)	 Stem wood (16.1. "Ristutukki")
 Forest residue, wet (10.12.2013)	 Stem wood (16.1)

Picture 3. Examples of raw data

During measurement intensive fuel sampling was made. Mostly six laboratory samples of each scanning batch of fuel were analyzed either in standard oven test and/or with BMA moisture analyzer (Senfit Oy) to get reference values for x-ray results. Some ash content analyzes were performed in UPM research centre Lappeenranta.

2.2 Share of foreign objects

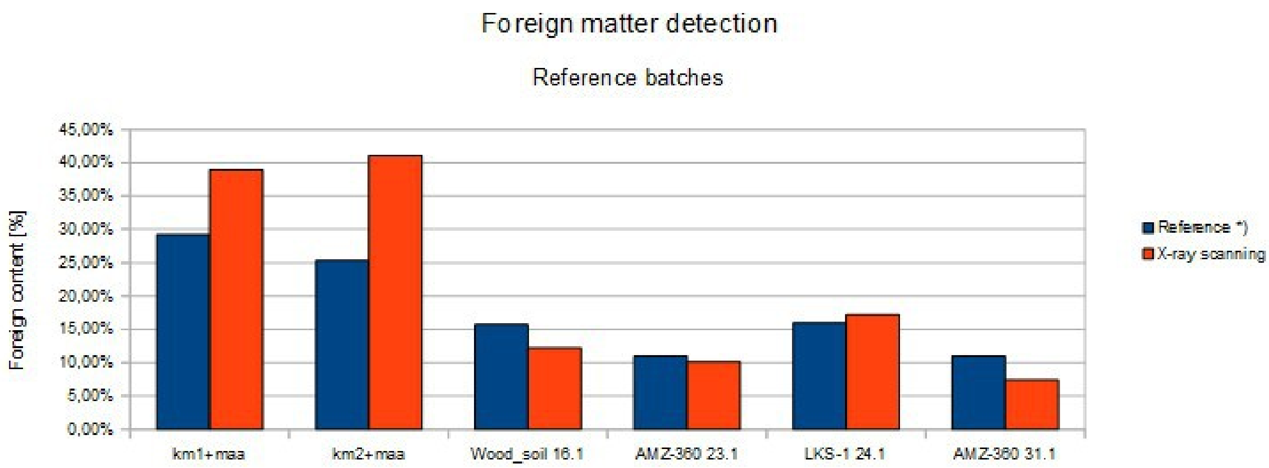
Shares of foreign objects were calculated from processed x-ray images. Three different groups were taken into account when calculating results for reporting, A1, A2 and A3. A1 contains share of pixels with highest densities which means that these pixels are most probably either steel (Fe), copper (Cu) or other high density metals. These are not common in Kaipola because of using biofuels and metal detector. A2 contains little bit lower density particles and these are most probably stone pieces and ice. A3 has density higher than average fuel (wood dry density 300-500 kg/m3) and one of main tasks of Inray at BEST program was to study and develop calculation of this group to reach better estimation of soil content of the fuel. Dry density of group A3 was estimated to be between 900-2000kg/m3 representing wide scale of foreign matter from ice to mud, soil and sand. Also moisture content of forementioned matters varies from 10-100% that makes they detection trickier.

Average densities used in calculation for different groups:

A1 7860 kg/m3 (steel)
A2 2750 kg/m3 (granite)
A3 2000 kg/m3 (wet soil)

For comparison, dry density of pine wood varies from 400...550 kg/m3.

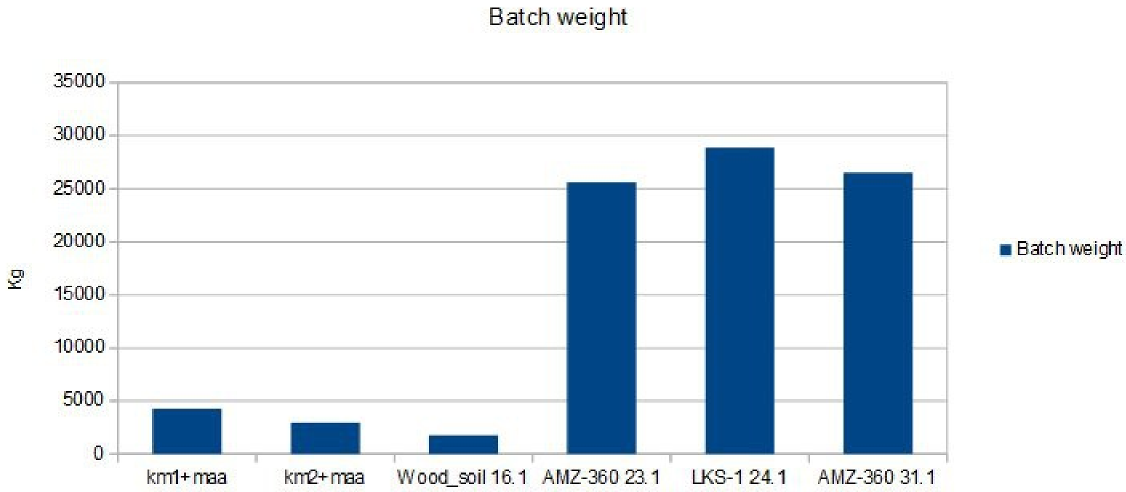
To find out how well different density groups define share of foreign objects some reference "dirty fuel" batches were prepared. Stump screening waste material that was weighted was mixed to known amount of clean chips. This mixture was scanned with x-ray. Another way that was used in studying potential foreign matter content included screening of representative amount of samples from same truck. After screening ash content analyses was done for different groups(UPM R&D). Screening result gave share of different particle size groups and combining this result to ash content analyses estimation for whole truck was calculated.



Picture 4. Test batches in foreign matter calculation tuning

First three batches were made with wheel loader and weight bridge so that known amount of “pure” chips were mixed with screening waste that was mostly wet soil. According to calculation first batch would have had approximately 29% soil content and second one 25%. However, on the same time x-ray detected soil and stones from “pure” precrushed stump chips so that average values for these two batches were 8.7% and 1.4% but it is hard to say does this number presents well amount of soil that ended up to the mixture. After summing potential soil content of pure chips and soil reference values could be 37.7% and 26.4%. The first one is actually almost same that x-ray calculation gave (table 2 row 2, 38.95%). For the second batch x-ray gives too high value for soil, 41% against calculated 25%.

On the other hand calculation gives relatively good results for last three trucks. Weights of studied test batches can be seen from Picture 5.



Picture 5. Weight of test batches

2.3 Studying of different stump batches

2.3.1 Crushed Stumps on 2.12.-3.12.2013

During 2.-3.12.2013 different stumps bathes were scanned to study effect of different pre-treatments. On 2.12 stumps were first time crushed in Kaipola whereas on 3.12 all batches had undergone some special pre-treatment like screening, pre-crushing etc. These pre-treatments had been made one month earlier so moisture of batches were slightly increased due to autumn rains.

Table 1 shows batch results of moisture and foreign objects on 2.12. On the left there exists date and batch name and after that there are columns for reference moistures that are average values of oven tests and/or BMA. Normal routine was to take six samples from each batch. On the right side of the table exists x-ray scanning results that are averages from whole scanning time of certain batch. "Stones&Metals" shows amount of higher density particles in the batch and Foreign_tot includes these plus soil.
“Moist Diff” tells difference between reference sample's average and x-ray's moisture.

Day	Batch	X-ray Moist Avg	X-ray moist std	Standard method avg	Stones&metals avg kg/min	Foreign avg kg/min	Foreign tot [kg]	Moist Diff
02.12.13	Kanto1	33,9	10,2	36,0	3,06	21,42	300	2,1
02.12.13	Kanto2	28,4	7,8	32,0	1,11	8,79	308	3,7
02.12.13	Kanto3	33,3	10,0	28,3	1,57	9,62	250	-4,9
02.12.13	Kanto4	30,3	8,6	28,0	0,61	7,12	242	-2,3
02.12.13	Kanto5	40,9	40,7	37,8	6,4	48,7	1266	-3,1

Table 1. Stumps on 2.12.2013

Day	Batch	X-ray Moist Avg	Standard method avg	Foreign avg kg/min	Foreign tot [kg]	Batch weight [kg]	Known soil mass	Estimated foreign [%]	Xray Foreign %(mass)	Foreign %(method2)	MoistDiff
03.12.14	km1	48,7	43,6	134	1177	7560	0	0,00%	15,57%	8,70%	-5,15
03.12.14	km1+maa	56,1	59,8	104	617	4240	1240	29,25%	14,54%	38,95%	3,78
03.12.14	km2	49,1	48,6	37	357	7080	0	0,00%	5,04%	1,38%	-0,55
03.12.14	km2+maa	54,5	52,4	83	330	2920	740	25,34%	11,29%	41,11%	-2,10
03.12.14	km3	53,0	43,4	59	407	2180	0	0,00%	18,65%	25,45%	-9,62
03.12.14	km4_kasanpohja	51,6	75,5	241	962	4220	0	0,00%	22,79%	15,97%	23,93
03.12.14	km5	56,6	50,5	28	278					1,49%	-6,06

Table 2. Precrushed and screened stumps on 3.12.2014

Column “Known soil mass” in table 2 presents amount of soil that was added to “pure” chips.

Column “Estimated foreign [%]” in table 2 shows calculated share of foreign matter. Calculation is based on weight.
Column “Xray Foreign % (mass)” shows Inray's result with conservative calculation algorithm and “Foreign % (method 2) results of more aggressive algorithm.

Naming of batches is based on scanning order so deeper analyzes batches has to be compared using thesis of Juho Salmi (“Kantoenergian laadun parantaminen esimurskauksella ja seulonnalla”, Helsinki University 2014).

Foreign matter content was calculated by two methods: The first one was noticed to give more conservative values for absolutely dirty mixtures and because of this second, more “aggressive” calculation was tuned.

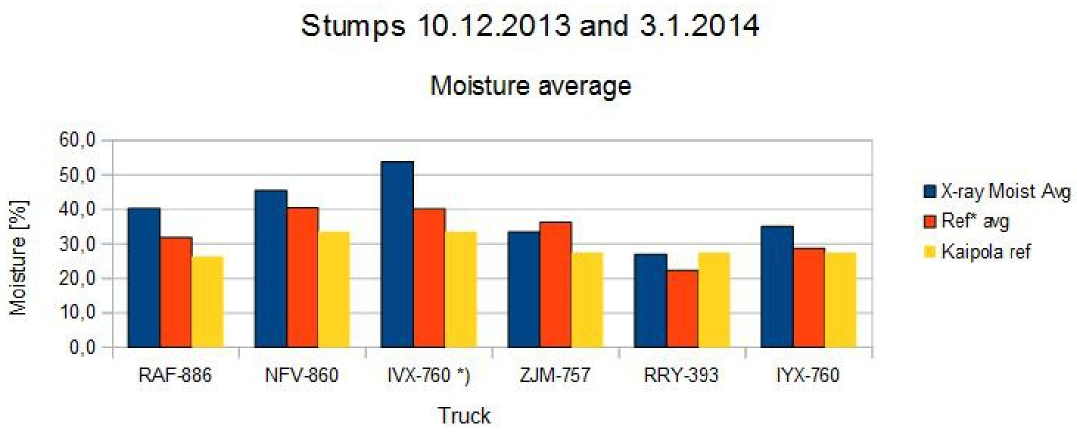
Main results of these two days were that crushed stump got wet during storage period and that screening doesn't remove all foreign matter. For example the first batch of 3.12 was mentioned to be clean after precrushing and screening but still it contained big amount of crushed rocks and even steel wires. So mainly soil was removed but bigger particles not. Reference batch was last batch "Kanto 5" on 2.12 and it had similar foreign matter content.

Different batches have different size so it's better to look either foreign matter flow in minute "Foreign average kg/min" or share of the foreign matters "Foreign % (mass)". On this basis cleanest batch was km5, dirtiest "km4_kasanpohja". “km4_kasanpohja” was made by collecting together fuel that was left on yard after picking km1, km2 and km3 so result is fairly clear.

2.3.2 Crushed stumps 10.12.2013 -5.2.2014

Day	Batch	X-ray Moist Avg	Ref* avg	Kaipola ref	Stones&metals avg/min	Foreign average kg/min	Foreign tot [kg]	Truck weight	Foreign % (mass)
10.12.13	RAF-886	40,3	31,8	26,5	3,1	51,1	1533	20040	7,65%
10.12.13	NFV-860	45,4	40,5	33,6	12,7	124,5	3735	18960	19,70%
10.12.13	IVX-760 *)	53,8	40,3	33,6	2,0	71,3	1069	25520	4,19%
03.01.14	ZJM-757	33,5	36,3	27,5	1,0	13,2	543	24560	2,21%
03.01.14	RRY-393	27,1	22,4	27,5	0,9	4,4	151	19000	0,79%
03.01.14	IYX-760	35,1	28,7	27,5	2,1	21,7	650	17300	3,76%
	Average	39,2	33,3	29,4	3,6	47,7	1280	20897	6,38%

Table 3. Crushed stumps on 10.12.2013 and 3.1.2014



Picture 6. Moisture comparison between x-ray and references

“Kaipola ref” presents power plant's own composite sample that is made from many truck samples taken by drivers.

Truck IVX-760 was marked as “dirty” and visually it showed to contain a lot peat. Only first part of the truck (car) was scanned but “Truck weight” is for whole combination. This means that most probably calculated “Foreign Mass” should be higher.

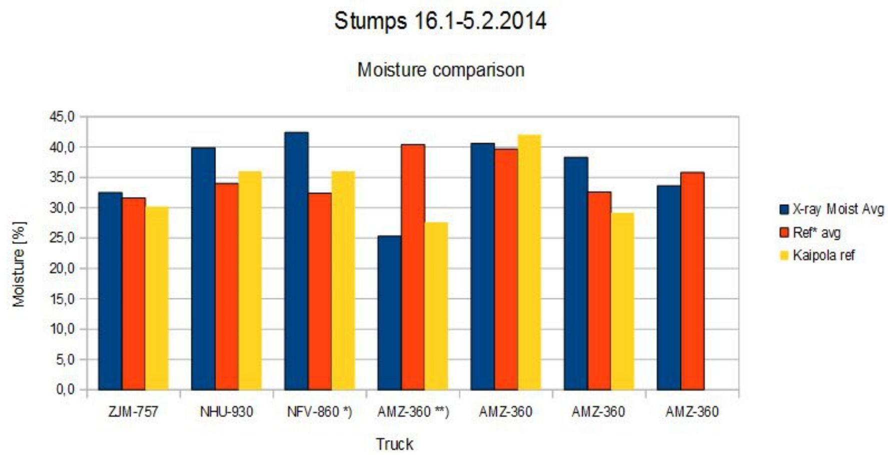
Further truck RRY-393 in table 3 earns special attention because it was clean and dry in every test method. Reason can be found from MWh/ton based prizing for this sub-contractor. Second notice can be placed for truck weight: RRY-393 was 19 tons, a bit more than bad quality batch NFV-860 in same table.

Day	Batch	X-ray Moist Avg	Ref* avg	Kaipola ref	Stones&metals avg/min	Foreign average kg/min	Foreign tot [kg]	Truck weight	Foreign % (mass)
16.1.2014	ZJM-757	32,5	31,6	30,2	4,0	67,8	3053	25660	11,90%
17.1.2014	NHU-930	39,9	34,0	36,0	0,9	81,3	2358	23360	10,10%
17.1.2014	NFV-860 *)	42,4	32,4	36,0	12,6	117,0	2809	9264	30,32%
23.1.2014	AMZ-360 **)	25,3	40,4	27,6	0,6	60,9	2192	25620	8,55%
24.1.2014	AMZ-360	40,6	39,7	42,0	2,0	201,3	7045	28880	24,39%
31.1.2014	AMZ-360	38,3	32,6	29,2	19,6	66,0	2442	26500	9,22%
5.2.2014	AMZ-360	33,6	35,8		0,6	29,9	1406	25620	5,49%
	Average	36,1	35,2	33,5	5,7	89,2	3044	23558	14,28%

Table 4. Crushed stumps 16.1-5.2.2014

*) About 30% of truck was scanned before blockage at conveyor.
**) Column "Ref avg": samples were forgotten in the oven and dry weight was taken after one week.

On January many terminal stump batches were driven through the x-ray scanner. Note that dirtiest batch on 17.1 (NFV-860) even blocked crusher and only about one third of it was scanned and “Truck weight” is estimate. 5.2 batch (AMZ.360) was undergone many “lift and release “ treatments on power plant as a part of power plant's own seperate testing. This batch had smallest foreign matter content but still it contained stone particles.



Picture 7. Moisture comparison of stump trucks from 16.1 till 5.2.2014.

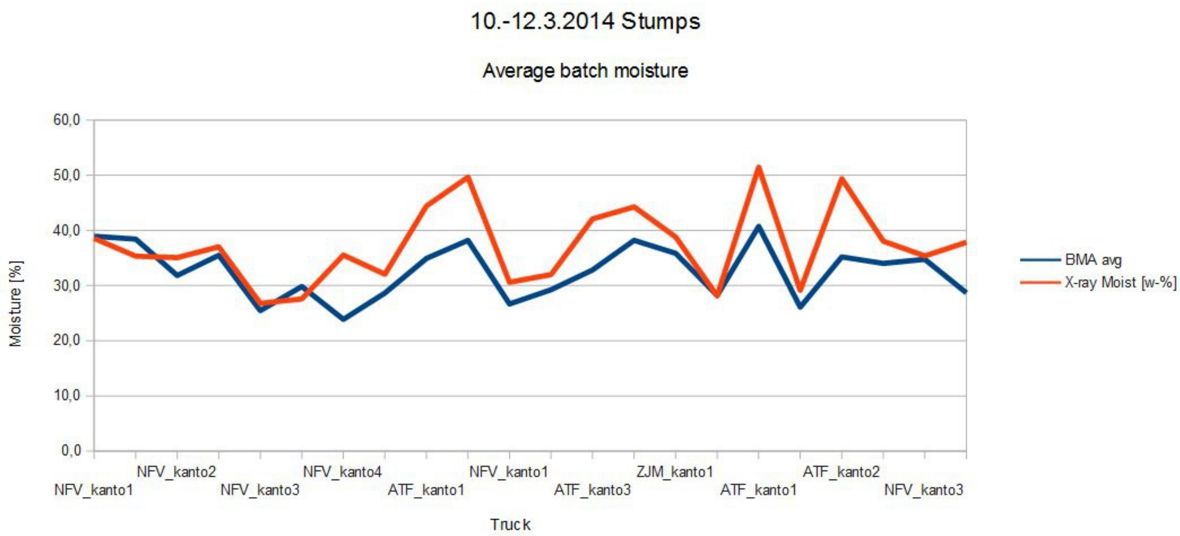
Truck AMZ-360 on 23.1: Samples were one week in oven.

2.3.3 Week 11/2014

Table below shows summary of scanned stump batches. As a general comment most stump batches were quite clean compared to some earlier batches on January and February. In some trucks x-ray moisture is much higher than in BMA which can indicate extra soil that wasn't found in actual foreign matter content calculation. This kind of batches are for example 10.3 NFV_kanto4 (differerence -11,6%), 11.3. ATF_kanto2 (-11,5%), 12.3 ATF_kanto1 (-10,7%) and ATF-kanto2 (-14,2%). Sample taker's commented all these samples from ATF trucks to be dirty.

	Date	Batch	BMA avg	X-ray Moist [w-%]	Foreign [kg]	Fuel tot [kg]	Foreign %	Difference
1	10.03.14	NFV_kanto1	38,9	38,5	2380	22240	10,70%	0,4
2	10.03.14	ATF_kanto1	38,4	35,3	782	18020	4,34%	3,1
3	10.03.14	NFV_kanto2	31,8	35,1	561	15400	3,64%	-3,2
4	10.03.14	ATF_kanto2	35,5	37,0	643	19640	3,28%	-1,5
5	10.03.14	NFV_kanto3	25,5	26,8	338	14080	2,40%	-1,3
6	10.03.14	ATF_kanto3	29,8	27,6	294	17020	1,73%	2,2
7	10.03.14	NFV_kanto4	23,9	36	287	15620	1,84%	-11,6
8	10.03.14	NFV_kanto5	28,7	32,1	303	17420	1,74%	-3,4
9	11.03.14	ATF_kanto1	34,9	44,4	608	19120	3,18%	-9,5
10	11.03.14	ATF_kanto2	38,2	49,7	1454	14320	10,16%	-11,5
11	11.03.14	NFV_kanto1	26,7	30,6	252	20660	1,22%	-3,9
12	11.03.14	NFV_kanto2	29,3	32,0	341	16440	2,08%	-2,7
13	11.03.14	ATF_kanto3	32,8	42,1	494	17940	2,75%	-9,3
14	11.03.14	ATF_kanto4	38,2	44,3	682	20240	3,37%	-6,1
15	11.03.14	ZJM_kanto1	35,9	38,8	1054	24600	4,28%	-3,0
16	12.03.14	NFV_kanto1	28,2	28,1	636	20960	3,04%	0,1
17	12.03.14	ATF_kanto1	40,7	51,5	1611	20480	7,87%	-10,7
18	12.03.14	NFV_kanto2	26,1	29,1	467	15160	3,08%	-3,0
19	12.03.14	ATF_kanto2	35,2	49,4	626	21040	2,98%	-14,2
20	12.03.14	ZJM_kanto2_11.3	34,0	38,1	592	23140	2,56%	-4,0
21	12.03.14	NFV_kanto3	34,8	35,4	345	19160	1,80%	-0,6
22	12.03.14	NFV_kanto4	28,7	37,8	425	19620	2,17%	-9,2
		Average	32,6	37,2	690	18742	3,64%	-4,7

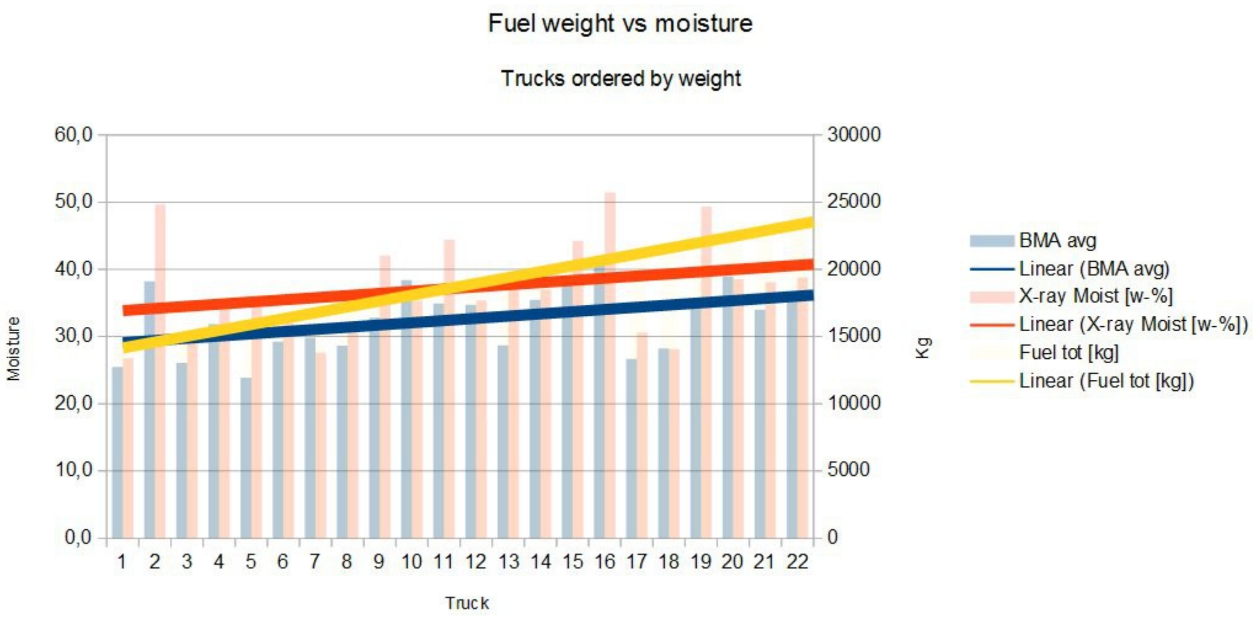
Table 7 Summary of measured stumps on week 11



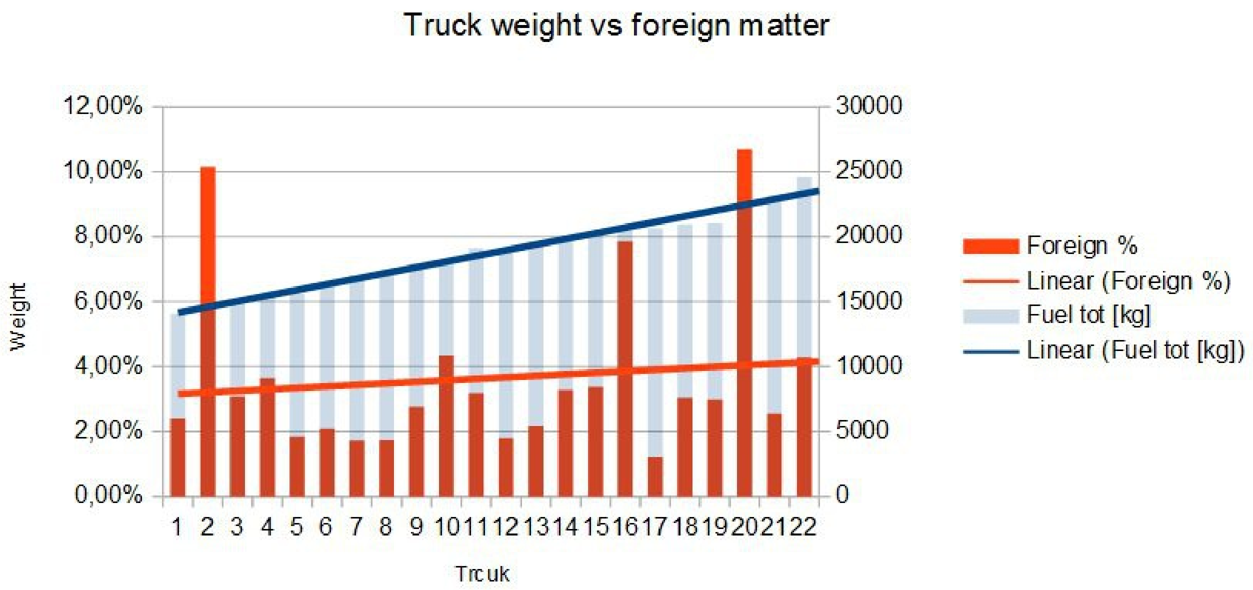
Picture 8. Moisture content of measured stump batches. Comparison between BMA and x-ray.

The average difference between 6 reference sample's average and x-ray's moisture was -4.7%. If three biggest differences are removed from average calculation the difference is -3.5%

Same measured stump trucks are ordered by load weight to study how easy/difficult it can be to estimate moisture and foreign matter content only by watching truck load.



Picture 9. Moisture of stump batches on week 11. Trucks ordered by weight.



Picture 10. Foreign matter content of stump batches on week 11. Trucks ordered by weight.

3. Summary and conclusions

About 50 stump batches are included to this report. Mostly six manual reference samples were taken from each batch to compare x-ray's online moisture calculation to standard method. Part of the reference samples were analyzed only with BMA (microwave). Measurements happened during ”wet” winter 2013-2014 when temperature was in normal winter level (-10...-20 ºC) only few weeks in January 2014. Mostly this meant that amount of snow in fuel was smaller than in normal years. However no difficulties were meet because of weather what comes to measurement system itself. On the other hand small changes were made to Kaipola crusher before intensity week and this was noticed also in x-ray data: Particle size after crusher was noticed to be smaller that produced more dense fuel mat to conveyor. Also overfill on belt raised more often after crusher changes and software was tuned to reject this kind of periods from calculation.

Moisture differences exists between references and x-ray that can be seen normal. Reference samples were taken six per truck load and because of moisture variations this amount of samples did not represent actual moisture content in all cases. There also exists measurement uncertainty of BMA analyzer used in some tests. Some batches could be measured more accurately with x-ray if the height of the fuel could be kept constant or height would be measured. In the future fuel level measurement will be added to system is places where it is possible.

In some stump batches moisture was measured higher with x-ray than reference sample's average and part of this difference can actually be soil content. So better result would have been lower moisture and some bigger amount of soil in x-ray's results but this can be improved in the future. On the other hand both moisture and soil decrease energy content of the batch.

Foreign matter detection worked for high density particles like stone and metals. Lower density particles like soil and sand include still development challenges what comes to either very small amount of soil, or higher than ~25% share of foreign. This was noticed in mixtures where calculated share of foreign matter was at the level of 25-30% and mixture wasn't even. On the other hand different types of soil with different moistures should be studied starting from very small percentage and growing percentage up to expected maximum.