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RFID Signal Penetration through Particulate Solids

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ABSTRACT:

Radio frequency identification technology is an automatic identification wireless communication technology that integrates physical objects with the digital data. It is dominantly becoming accepted in supply chain management, which includes all processes in the flow of goods to customers from manufacturing, which consists of manufacturing, distribution and transportation. This research paper focuses on the readability of RFID penetration in different particulate solid products with varying particle sizes. In addition simulation during transportation is performed on a conveyor belt at different speeds. Variable factors in this experiment were different types of particulate solids of different particle sizes, packing density, and tag position. Data are analyzed using N^K Factorial design to observe the significance of the main factors.

Introduction:

Supply chain includes all processes that involve the flow of goods to customers from manufacturing, which includes transportation, manufacturing and distribution. Therefore by covering all the above steps in connection with demand of customer, marketing decisions, in alignment with general corporate goals and strategy. Commonly considered as a complex and knowledge demanding process, management of supply chain can interest significantly with the implementation of RFID technology [1].

RFID technology has grown to become a innovative element in supply chain management. RFID is not just a substitution for barcodes. RFID ensures that accuracy in inventory control and real time product information available to make decisions. It makes the supply chain significantly more accurate and improves the reliability and efficiency of the entire chain. As real-time information is made obtainable, planning and administration processes can be extensively improved as well [1]. Applying RFID technology will result in less manual work, improved visibility, improved planning and less costs.

RFID is a technology that incorporates electromagnetic in the radio frequency (RF) portion of the electromagnetic spectrum to distinctively identify an object. It is coming into increasing use in industry as an option to the bar code. RFID does not require line-of-sight or direct contact for scanning which will be the major benefit for supply chain. There are three components in an RFID system: RFID tag, RFID reader and an antenna (also called transponder). The antenna emits radio frequency waves to broadcast (transmit) a signal that energizes tag and in return a signal response is received [2, 3].

Problem statement:

Packaging industries using RFID technology may face the problem of missing the item count of products during processing due to different product characteristics such as chemical composition, density etc. This research paper examines the use of RFID in packaging industry where the items are of different particulate solids of different packing densities. This is important in supply chain because transportation can change the product's physical characteristics. In this paper particle shape, size and packing density are investigated to determine its effects on RFID tag readability. Particle size is considered as an important characteristic since it effects the properties such as surface per unit volume and rate of settling of particles. The shape of the particle may have an effect on packing characteristics [5].

Equipment and Methodology:

Equipment:

Equipment used in this research are the rectangular standardized cell of size 6in x 10in x 1.25 is fabricated using 0.25in thick Lexan material supported on a HDPE frame (Fig. 1). This holds the particulate solid and the volume of the container is 934ml (934 CC). An Alien RFID reader (Fig. 2.1) (ALR-9800) is used. The reader's function is to interrogate RFID tags. Supported RFID tag protocols are ECP Class 1 Gen 2, ISO 18000-6c. Alien reader protocol is autonomous mode which has upgradeable architecture for future EPC reader protocols [4]. An RFID tag reader uses antennas (fig. 2.2) to communicate with the RFID chip. Tag used in this experiment was a passive tag (fig.2.3).These tags have a useful life of twenty years or more and also not expensive to manufacture. Vibrating table *Syntron Power Plus #225484A [6]* handle tough material to condense, settle, dandify, de-airing and packing.

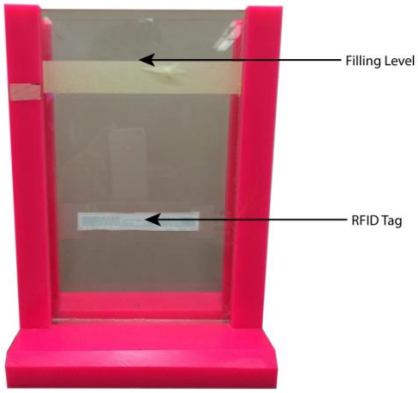


Figure 1: Container to hold particulate solids

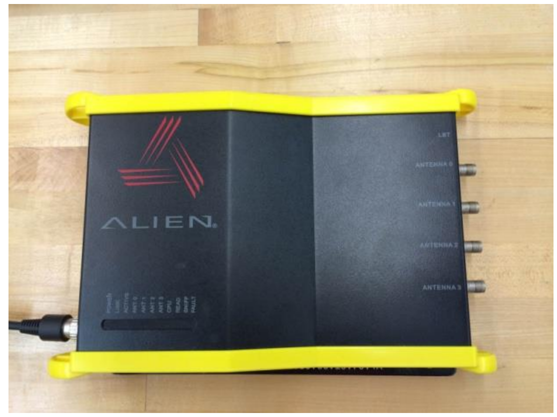


Figure 2.1 Alien ALR9800 RFID reader [4]

Figure 2.2 External Circular Polarized Antenna [4]

Figure 2.3ALN-9640/9740 Tag [4]

Figure 2: RFID components

Experimental setup:

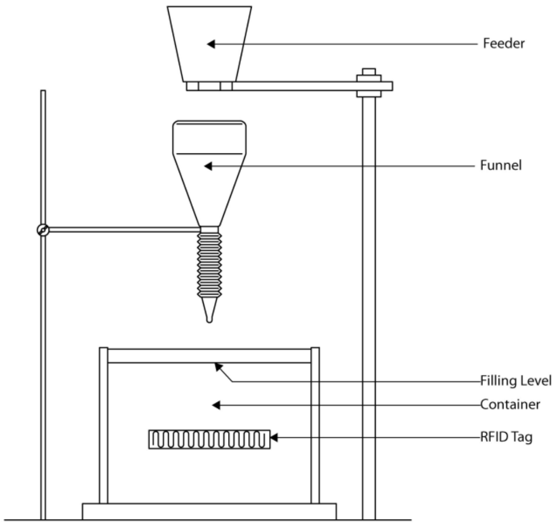
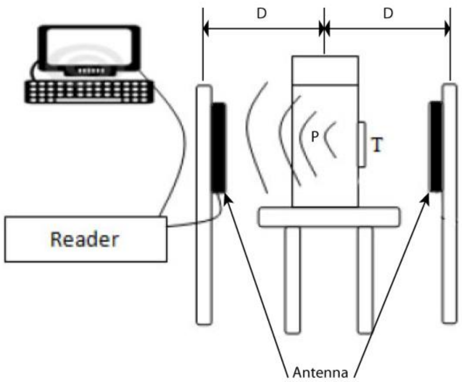


Figure 3: Filling of particulate product



D - Distance from antenna to container, 13 in.
T - Tag
P - Particulate solids

Figure 4: System setup RFID Equipment

Methodology:

Two different particulate solids, rice and salt were tested at different packing densities. To understand the impact of particulate solids on tag readability of RFID signals, experiments were performed, with tag placed on near side and far side of the cell (Fig. 4). This position simulates the package with a tag away from antenna or towards the antenna. The cell containing the solid was kept at constant distance from the antenna. The material was loaded using funnel method shown in figure 3. This allowed free flow of material into the container without excessive packing. The amount of material in the container was measured by weight. Tag readability readings were noted for both rice and salt under this condition. The container with material was then vibrated for one minute, the space created due to packing was replenished and continued vibration until no weight change was observed. Table 1 shows the data gathered. Tag readability was checked again for the packed product. All RFID readings were taken for 20 seconds to meet FCC regulation [7].

Design of Experiments (DOE) methodology was used to analyze data using 2^3 factorial design (2-levels, 3-factors). DOE is a dominant tool that allows for several input variables or factors to be manipulated determining their effect on a desired response (input). By changing multiple inputs, DOE can recognize important interactions that may be lost when experimenting with one factor at a time. The factors investigated here are, particle size, packing density, and tag position. All possible combinations are investigated using full factorial design [8].

Experimental Data and Analysis:

The density values for the two materials are shown in Table 1. The packing density increased from 2.057 g/cm^3 to 2.211 g/cm^{3}for salt and for rice it increased from 1.530 g/cm^3 to 1.600 g/cm^3. Table 2 shows the factors (particle type, density and tag position) and their respective levels. Design matrix for the experiment is given in table 3 which gives the order in which the experiments were performed. Each experiment was performed four times and the data was recorded (Table. 4).

Table 1: Packing density before and after vibration.

	Pre vibration		Post vibration	
	Salt	Rice	Salt	Rice
weight, g	1921	1429	2065	1494
Volume, cm^3	934	934	934	934
Pack. den g/cm^3	2.057	1.530	2.211	1.600

Table 2: Input factor and levels investigated

		Name	Low	High
Factor	A	Type	Rice	Salt
Factor	B	Density	Free	Tap
Factor	C	Tag Position	Front	Back

Free = Free flow density

Tap = Tap density (after vibration)

Table 3. Design matrix for the factor investigation.

Std Order	Runs	A	B	C	AB	AC	BC	ABC
1	1	Rice	Free	Front	+	+	+	-
a	2	Salt	Free	Front	-	-	+	+
b	3	Rice	Tap	Front	-	+	-	+
ab	4	Salt	Tap	Front	+	-	-	-
c	5	Rice	Free	Back	+	-	-	+
ac	6	Salt	Free	Back	-	+	-	-
bc	7	Rice	Tap	Back	-	-	+	-
abc	8	Salt	Tap	Back	+	+	+	+

Table 4: Output from the experimental data (four replicates).

		A	B	C								
Std Order	Runs	Type	Density	Tag Position	1	2	3	4	Sum	Avg	Std Dev	Variance
1	1	Rice	Free	Front	50	41	46	56	193	48.25	6.344	40.250
a	2	Salt	Free	Front	105	109	107	108	429	107.25	1.708	2.917
b	3	Rice	Tap	Front	89	82	42	65	278	69.50	20.920	437.667
ab	4	Salt	Tap	Front	148	145	145	143	581	145.25	2.062	4.250
c	5	Rice	Free	Back	135	138	143	140	556	139.00	3.367	11.333
ac	6	Salt	Free	Back	149	140	145	149	583	145.75	4.272	18.250
bc	7	Rice	Tap	Back	80	86	86	82	334	83.50	3.000	9.000
abc	8	Salt	Tap	Back	107	93	93	98	391	97.75	6.602	43.583
					Df =	*24*		Sum	3345.00	836.25		567.250
								Divisor		8		8
									Means	104.531		70.906
									StDev exp		8.421	

Table 4 shows the summary data and standard deviation for the response data, and the standard deviation for the entire experiment which is 8.421. Table 5 gives the summary of all the calculated values along with the effects. Factors A and C has the most effect and combination of all three factors, ABC has the least effect on the yield of the experiment conducted.

Table 5: Effects summary of calculations:

	Factors:	A		B		C		AB		AC		BC		ABC	
	Names:	Type		Density		Tag Position									
Std Order	Average	Rice	Salt	Free	Tap	Front	Back	-1	+1	-1	+1	-1	+1	-1	+1
1	48.25	48.25		48.25		48.25			48.25		48.25		48.25	48.25	
a	107.25		107.25	107.25		107.25		107.25		107.25			107.25		107.25
b	69.50	69.50			69.50	69.50		69.50			69.50	69.50			69.50
ab	145.25		145.25		145.25	145.25			145.25	145.25		145.25		145.25	
c	139.00	139.00		139.00			139.00		139.00	139.00		139.00			139.00
ac	145.75		145.75	145.75			145.75	145.75			145.75	145.75		145.75	
bc	83.50	83.50			83.50		83.50	83.50		83.50			83.50	83.50	
abc	97.75		97.75		97.75		97.75		97.75		97.75		97.75		97.75
Total	836.25	340.25	496.00	440.25	396.00	370.25	466.00	406.00	430.25	475.00	361.25	499.50	336.75	422.75	413.50
n	8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Avg	104.531	85.063	124.000	110.063	99.000	92.563	116.500	101.500	107.563	118.750	90.313	124.875	84.188	105.688	103.375
Effect			38.938		-11.063		23.938		6.063		-28.438		-40.688		-2.313
Half Effect			19.469		-5.531		11.969		3.031		-14.219		-20.344		-1.156

Table 6: Effects Decision Limit (DL).

Confidence Interval	Df	t Statistic	StdDev Eff.	DL
0.95	24	2.064	2.977	6.144

Factor	Effect	DL	Effect>DL	Include in Model
A	38.938	6.144	Yes	Yes
B	11.063	6.144	Yes	Yes
C	23.938	6.144	Yes	Yes
AB	6.063	6.144	No	No
AC	28.438	6.144	Yes	Yes
BC	40.688	6.144	Yes	Yes
ABC	2.313	6.144	No	No

t-statistic is calculated for alpha risk of 5 percent. From table 4 degrees of freedom (df) is 24, using t-table, the t-statistic value is 2.064. Decision limit (DL) for significance of effect (here it is 95% confidence interval) in this experiment can be calculated to compute and determine the effects are significantly different, and not due to random variation. If the effects are outside the zone defined by the decision limits, they are considered significant. DL is calculated by, DL= ±(t statistic)*(StdDevEff.).

Therefore all the effects in table 6 which exceed the DL are judged to be significant. Since the interaction effect is significant, consider these factors for optimization. To depict the relative importance of the effects absolute values are plotted as a Pareto chart (fig.5) [9].

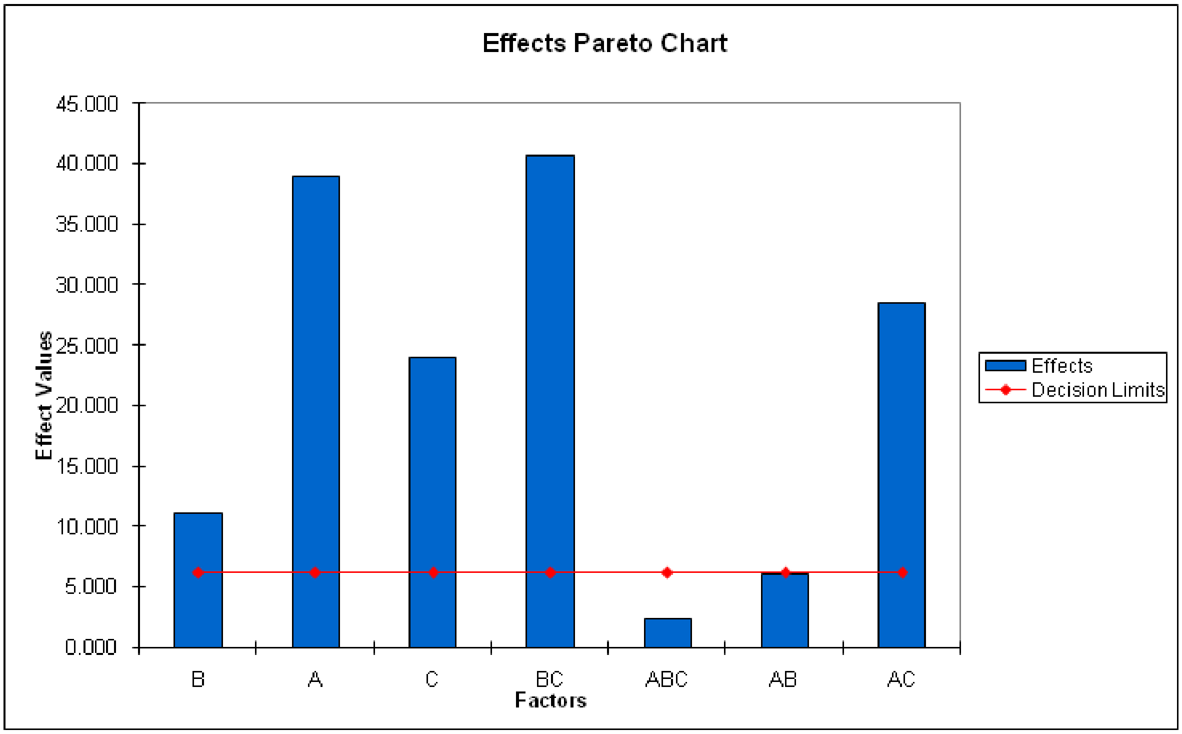


Figure 5: Pareto chart for the factors.

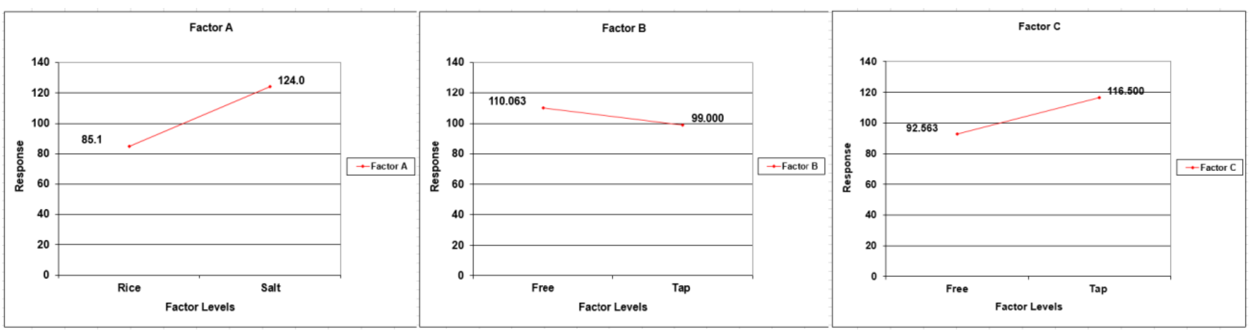


Figure 6: Main effects plot

Main effects are defined as the difference in the average response between the high and low levels of a factor. Factor A has the largest change of 38.938 units and factor B is the lowest. Therefore, factor A should be considered during optimization.

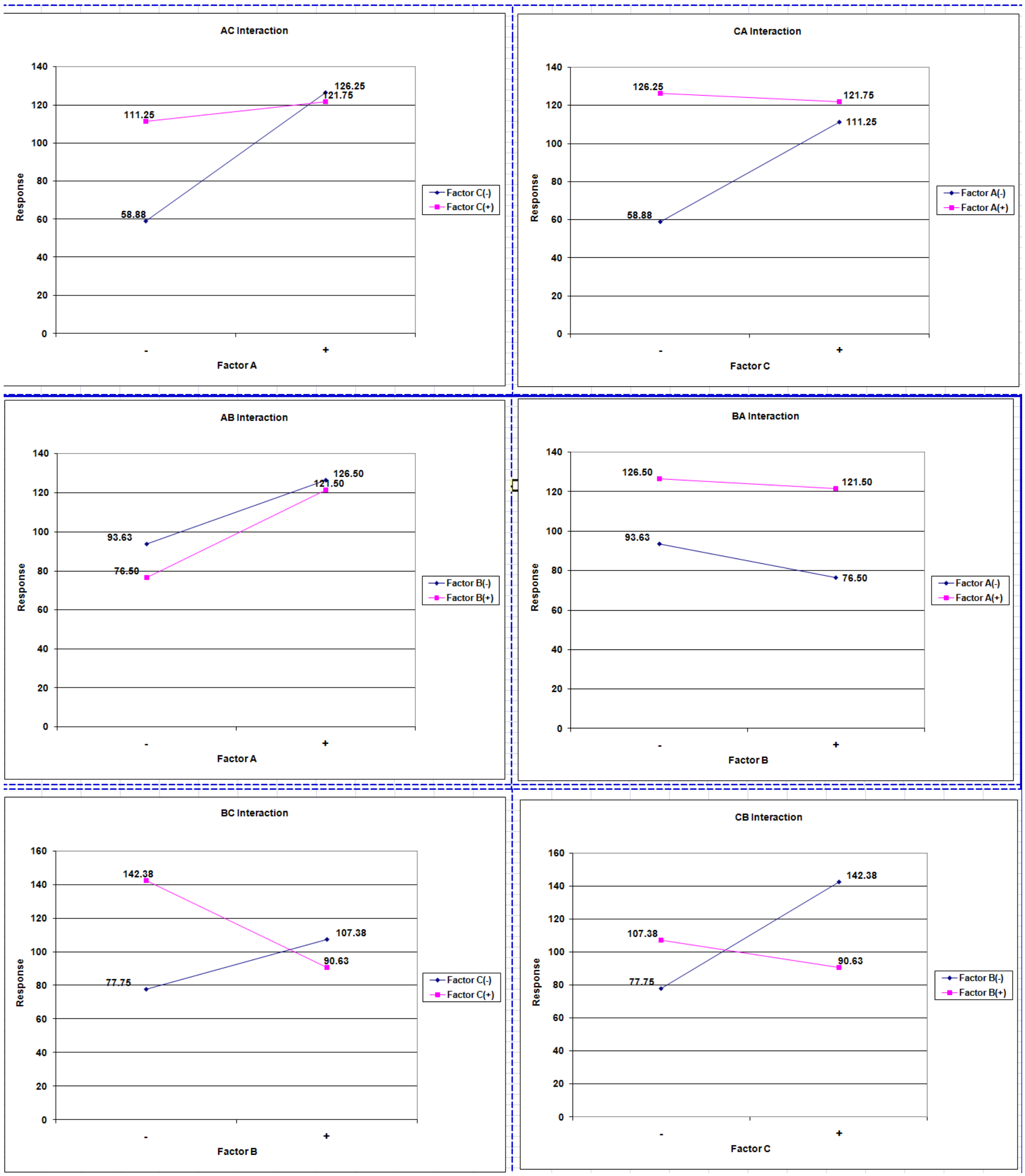


Figure 7: Interaction chart

An interaction occurs when a particular combination of two factors behave unexpectedly. An interaction is defined as one-half of the difference between the effect of A at the high level of B and the effect of A at the low level of B. If an interaction proved to be significant, the interaction chart is very important. The BC interaction is significant as seen in figure 7.

Conclusion:

Of the main factors, factor A (type of material) and C (tag position) exceeds the decision limits and judged to be significant. Since the interaction effect BC was significant during optimization process both factors must be considered. This becomes important in practice because during transportation of particulate products the density is subjected to change. Therefore, if RFID is used for tracking and inventory control the changes in density must be considered. Since the tag position is also a major factor, placement of the tag needs to be optimized. Further research on optimization needs to be carried out.

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