Establishing the Amount of Grain Breakage Taking Place in Bulk Maize during Conveyance through the Drag Chain Conveyor

Mwaro, W.B, Maranga, S.M, Ikua, B, Kanali, C.L

Abstract - The continued increase in human population in the world has continued to put pressure on the available food resources. In this regard, the need to uphold high quality standards in food grains has continued to be paramount. Grain damage during conveyance in bulk through a grain handling facility is of great concern and various studies have been carried out to establish the extent to which various equipment in the handling facility do contribute to grain breakage. In this study, the amount of grain breakage taking place during conveyance of bulk grain through the drag chain conveyor with steel flights was established. Samples of maize grains were obtained from a selected number of drag chain conveyors in three grain handling facilities at the National Cereals and Produce Board and the amount of broken grains was established through a standard procedure. The results showed that a drag chain conveyor with steel flights can cause up to 2.63% grain breakage in bulk maize grains during conveyance. It was also established that grain breakage increases with decrease in conveyor loading and grain moisture content. Grain breakage was also found to increase with repeated handling. The findings in this study will aid in the selection of the grain handling equipment as well as in the design improvement of the drag chain conveyor system.

Key words- Drag chain conveyor, Grain breakage, Grain handling facility, Grain quality.

1. INTRODUCTION

A big section of post-harvest losses in food grains are as a result of poor grain quality. Amongst the various quality properties of food grains are the physical quality traits which include moisture content, kernel size, total damaged kernels, broken kernels, stress cracking and breakage susceptibility. These quality parameters are mostly affected by among other factors the grain genetic traits, grain harvesting and handling systems, drying system, storage management practices and transportation.

Grain breakage is perhaps the major course of quality deterioration and grain loses. It is part of physical damages occurring in grains and is defined as a breakage of the endosperm or rupture in the seed coat [1]. The Kenya Bureau of Standards (KEBS) defines broken maize grains as any maize grains or maize fragments which will pass through a 6.35mm minimum round-hole sieve when shaken [2]. Plate 1.0 below differentiates between whole maize grains, broken maize grains and extremely broken maize grains (or maize dust). Maize dust refers to fine particles of maize grains which are generated by further breakage of the already broken maize grains

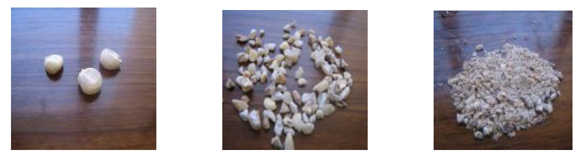

Figure 1.1 (a) Whole grains (b) Broken maize (c) Maize dust

Grain breakage in maize can result from impact during harvesting, shelling or handling and sometimes from abrasion and compression of kernels during transportation in augers and drag chain conveyors. It is specifically influenced by maize variety, moisture content of the grain, drying temperatures and cooling procedures. A small percentage of breakage in maize grains is caused by insects and rodents [3].

The focus of this study was to establish the amount of grain breakage taking place during conveyance of bulk maize grain through the drag chain conveyor system with steel flights.

2. LITERATURE REVIEW

2.1. Effects of Grain Breakage on Maize Grain Quality

Broken maize grains in storage is more vulnerable to microorganisms, insect infestations, fungal activities and growth of microflora. It has a high rate of respiration hence leading to weight loss and a decrease in its overall allowable storage time [4]. During storage, large amounts of broken maize grains contribute to high resistance to free airflow during aeration leading to the formation of hot spots. It can also lead to dust explosion, health hazards and hygiene problems [5].

In the maize milling process, high levels of broken maize kernels lead to starch damage and loss of oil as well as lowering the nutritional value of maize processed for livestock feeding [6]. Broken maize kernels also lower the yield of maize meal and flour [7] - [8]. During the cleaning process, broken maize grain kernels are removed with other impurities causing major processing losses while those that escape to the conditioning stage end up taking in moisture rapidly hence disintegrating into very small particles leading to a much lower extraction rate. The cost associated with handling of maize dust and broken pieces, loss of marketability and cost due to downgrading of the maize grains also adds to the overall storage cost of maize as food grains [4].

W.B. Mwaro, Department of Mechanical Engineering, at JKUAT, Phone; +254725 922573; fax: +2546752711; e-mail: mwaro@eng. jkuat.ac.ke.

2.2. Grain Breakage During Handling

A Typical grain handling system is composed of various equipment arranged in a given manner such as to facilitate the effective movement, conditioning and storage of the grain. Grain transfer through the handling system involves a combination of horizontal movement, a lift and/or a drop through some form of mechanical conveyor, elevator or chutes.

At every stage of conveyance however, maize grain kernels are repeatedly impacted, compressed or pitched against hard surfaces as they go through grain throwing and conveying equipment such as screw conveyors, chain conveyors, chutes and bucket elevators. Impact damage also results from free falls into deep silos [4]. According to [9], repeated handling of maize grains also affects its physical quality and leads to breakage. Various researchers in the past have established the amount of grain breakage taking place during conveyance of maize grains through various sections of the grain handling system.

By passing maize grains through a screw conveyor rotating at various speeds, [10] established that when a screw conveyor is operated at full capacity, maize grain (corn) breakage was less than 0.1% but when operated at one-fourth capacity, breakage ranged from 0.1% at 275rpm and 0.7% at 875rpm.

Maize grain breakage in bucket elevators was reported by [11]-[12] for studies from the same research investigation. The study involved damage associated with the intake feed configuration and the elevator belt speed. In general, the grain damage was between 1.0 to 1.2%. Half-filled buckets increased breakage by 0.2% point compared to full buckets and no apparent effect was observed on corn kernel damage due to the difference in belt speed. The bucket elevator damage determined in a study by Hall (1973) included damage from both the intake and head sections. He found little difference in the up-viz-down leg feeding but increased fines developed when the feed rate was 25% of the rated capacity [9].

Grain breakage in grain silos is mostly associated with impact of grains against hard silo walls and against other grains as a result of free-fall, [12] studied grain breakage in maize (corn), wheat, soybeans, and dry edible peas caused by commercial handling methods. The variables of interest in this study were free-fall height, impact surface, corn moisture content and temperature. They observed that maize grain kernels (corn) dropped from a height of 12 m onto other maize grains at rest caused 4.3% breakage with 12.6% moisture content at -3.8°C, and 0.25% breakage with 15.2% moisture content at -5.0°C. [11]- [12] reported a threshold drop height value of 12.2m in terms of impact damage to maize grains. This threshold height represented a critical value in maize grain impact velocity, above which breakage due to impact increased quite sharply. The quality of the corn with respect to its brittleness and existing stress cracks had the effect of lowering this threshold value [3].

Grain breakage in pneumatic conveyance is mostly due to turbulent interchange in the flow pattern, Impact of grain with each other and with pipe wall, Impact at elbows i.e. change in direction, crushing at airlock feeder. By using a physical model of a pneumatic conveyor, [1]-[12]-[13] found out that maize grain breakage in pneumatic conveyors is related to the conveying velocity which in turn determines the grain-to-air ratio. These studies specifically indicated that conveying maize grains at velocities higher than 27m/s will lead to an increase in grain breakage [14] found that breakage susceptibility of shelled corn increased significantly during handling in pneumatic conveying systems with approximately 100-mm-diameter pipe. Chung *et al* (1973) reported on the effect of moisture content, system length, conveying air velocity, kernel size and shape factors on corn damage in pneumatic conveying systems [15].

Drying doesn't cause marked physical damage but if carried out too rapidly and at high temperatures; it leads to the formation of stress cracks, puffiness and discoloration hence promoting breakage susceptibility in maize grains [8] - [16].

2.3. The Drag Chain Conveyor System

The drag chain conveyor is one of the major grain conveying equipment in the grain handling facility. It's an all steel construction usually completely enclosed but provided with connection for grain inlet, outlet and dust extraction. It's used for horizontal or slightly inclined transport of grain for short and medium range distances. The drive terminal carries the drive station consisting of electric motor, transmission, drive shaft mounted in bearings, sprocket and an end outlet. The tension terminal is the tail section that is made up of a sprocket wheel mounted in roller bearings and designed to slide in guides with 2 spindles for tightening the chain. Figure 2.12 below shows a drag chain conveyor.

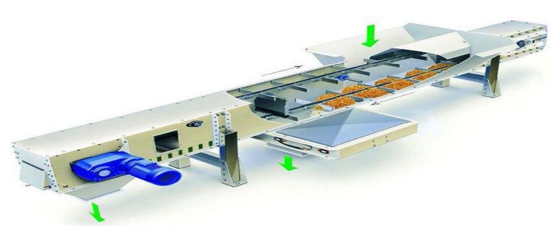

Figure 2.1: The drag chain conveyor systems.

The working part of the drag chain conveyor system is the drag chain. It is an assembly of chain links with weld on flights and hardened steel connection pins. The operation of the chain conveyor is such that grain is fed into the chain conveyor through any of the inlet spouts and falls to the conveyor trough floor. The advancing flight of the moving chain catches the grain and drags it en-mass steadily moving forward, until it encounters the first open outlet into which the grain drops and is effectively discharged from the chain.

Maize grain breakage in the drag chain conveyor system was evaluated with two drag chain conveyor units by [17]. One of the units was flat bottomed while the other was round-bottomed u-trough design. The flights were made from high-density polyethylene and were spaced approximately 53.3cm apart. Each of the unit had a 50ton/hr flow rate and was operated at 30.8m/min and 52.7m/min respectively. Three repeat cycles were made with each test and the damage for the three transfer cycles for each conveyor was divided by three reducing the implied damage to 0.06 and 0.03%, respectively for the natural dried corn and 0.15 and 0.25% for the commercial corn. They concluded that the level of damage was sufficiently low not to cause any serious concern [3].

While the study by [17] was an eye opener into how much maize grain breakage takes place during conveyance across the drag chain conveyor system, it did not consider the effect of using different flight materials on grain breakage. It is in this background that this study was aimed at establishing the extent of maize grain breakage in the drag chain conveyor system with steel flights.

3. MATERIALS AND METHODS

3.1. Research Design

The study was carried out through various experiments which were carried out on randomly selected grain handling plants found at the National Cereals and Produce of Kenya. The experiments were aimed at establishing the level of grain breakage that takes place during conveyance of maize grains through the drag chain conveyor. Data obtained thereby was recorded in various tables and analyzed using simple statistics.

3.2. Data Acquisition and Analysis

In doing the experiment, the discharge conveyor at the bottom of the grain silos was cleaned by allowing the drag chain to run for about 20minutes without load in order to ensure all maize grain settling in the conveyor has been removed. The bottom shutter to the grain silo at the extreme end of the drag chain conveyor was then opened and bulk maize grain allowed to flow out of the bin by gravity while the conveyor was moving at a constant speed. At the entry and the exit of the conveyor, a sample of maize grain weighing about 800grams was collected and taken to the laboratory for testing.

In the laboratory, the maize grain was put through a grain divider to ensure uniform mixing of the maize grain and subsequently divide the sample into four portions. From one of the four potions, a standard sample of 200grams of maize grain was weighed on a *Three Beam Balance - 2610grams* weighing scale with three output display scales (i.e.1-10, 10-100 and 100-1000). The weighed sample was then transferred into a digital moisture computer (meter) type *BURROWS MACHINE model: 700* from which the moisture content in the maize grain sample could be read directly from a digital display. A sample weighing 100grams was then weighed out of the second potion from the grain divider and transferred into a Standard 4.5mm *Round Hole Sieve No.27310* for sieving off all fines and broken maize grains. All the broken and fine maize grains which managed to go through the sieve was then weighed to ascertain its weight. The weight of the fines and broken maize grains was divided by the original sample weight (200grams) and multiplied by 100 to obtain the percentage of the fines and broken maize in the sample of 200grams.

$$\%BMG = \frac{mass\ of\ fines\ and\ broken\ grains}{original\ sample\ weight} \times 100$$

Where

$\%BMG$ - is the percentage of the broken maize grain in the sample.

The above test was repeated for all the ten drag chain conveyors at the three stations and the results are tabulated below.

4. RESULTS AND DISCUSSION

4.1 Results from the Three Stations

Tables 4.1.2, 4.2 and 4.3 below show the results of the experiments carried out on ten randomly selected drag chain conveyor systems at three NCPB stations. Column three and five of each table shows a record of the amount of maize grain breakage at the entry and exit points of the specific drag chain conveyor system. It should be noted that the drag chain conveyor number indicated in column two does not necessarily mean that the conveyors are arranged in series. In some cases the maize grain had to be moved into other grain handling equipment such as chutes, bucket elevators before entering the drag chain conveyor selected for the test.

Table 4.1
Results for Eldoret Silo Complex

KEY
C.No: Conveyor Number
MC: Moisture Content
CL: Conveyor Length

S/No	C.No.	% at Entry	% MC	% at Exit	% MC	CL
1	CC24	3.5	12.2	7.8	12.2	31M
2	CC23	2.8	11.8	6.4	11.8	22M
3	CC21	10.0	9.9	12.0	9.9	30M
4	CC20	1.5	10	2.5	10.0	10M
5	CC19	2.5	12.5	2.9	12.5	14M
6	CC18	1.6	12.7	3.0	12.7	10M
7	CC17	0.2	9.9	2.2	9.9	8M
8	CC26	0.2	12.7	3.1	12.7	10M
9	CC27	2.0	12.8	3.0	12.8	22M
10	CC29	2.0	12	7.0	12.0	10M

Table 4.2
Results for Moi's Bridge Silo Complex

S/No	C.No.	% at Entry	% MC	% at Exit	% MC	CL
1	CC20	2.5	9.4	8.3	9.4	15M
2	CC23	3.0	10.1	6.4	10.1	25M
3	CC19	2.1	9.5	7.9	9.5	30M
4	CC27	6.7	9.0	11.0	9.0	30M
5	CC16	5.6	10.7	13.1	10.7	25M
6	CC12	9.4	12.4	10.3	12.4	25M
7	CC02	6.8	10.3	13.4	10.3	15M
8	CC04	5.6	9.7	12.5	9.7	15M
9	CC06	4.5	10.1	8.3	10.1	20M
10	CC31	3.9	11.7	4.5	11.7	15M

Table 4.3
Results for Nairobi Silo Complex

S/No	C.No.	% at Entry	% MC	% at Exit	% MC	CL
1	CC10	3.0	12.2	6.0	12.2	18M
2	CC13	4.5	12.0	4.5	12.0	15M
3	CC14	2.9	12.0	3.0	12.0	15M
4	CC22	3.5	11.0	3.8	11.0	20M
5	CC20	1.6	13.0	2.1	13.0	15M
6	CC29	2.0	12.5	2.5	12.5	15M
7	CC30	4.0	10.0	4.9	10.0	15M
8	CC21	3.0	9.9	4.3	9.9	10M
9	CC23	3.2	10.1	4.2	10.1	10M
10	CC08	4.9	12.0	7.2	12.0	20M

4.2 Effects of Conveyor Loading on Grain Breakage

In order to ascertain the effects of loading on grain breakage, a conveyor was randomly selected from the grain handling plant at Eldoret Silo complex. The conveyor was first loaded to full capacity and samples collected randomly at different points starting with the conveyor entry towards the exit. The samples were then analyzed for grain breakage as per the procedure in section 3.2 and the results were recorded as shown in the tables below.

Table 4.4
Grain Breakage for conveyor loaded at full capacity

S/No	Test Point	% Breakage	MC (%)
1	At entry	4.2	10.6
2	3m	4.2	
3	5m	5.0	
4	7m	5.1	
5	9m	4.9	
6	12m	5.0	
7	15m	5.6	
8	18m	5.8	

Table 4.5
Grain Breakage for conveyor loaded at ¼ of full capacity

S/No	Test Point	% Breakage	MC (%)
1	At entry	4.2	10.6
2	3m	6.5	
3	5m	7.2	
4	7m	8.0	
5	9m	8.6	
6	12m	8.6	
7	15m	8.7	
8	18m	8.8	

4.3 Data Analysis

Considering the percentage change in grain breakage at entry and exit of the drag chain conveyors for the various stations, graphs of sample number against percentage grain breakage were plotted as shown below.

Table 4.6
Data extract for Eldoret Silos

S/No	% at Entry	% at Exit
1	3.5	7.8
2	2.8	6.4
3	10.0	12.0
4	1.5	2.5
5	2.5	2.9
6	1.6	3.0
7	0.2	2.2
8	0.2	3.1
9	2.0	3.0
10	2.0	7.0

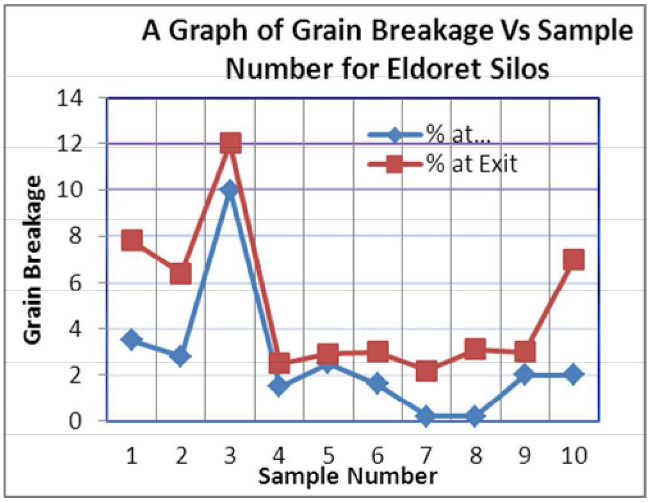

Fig. 4.1 A Graph Showing % Grain Breakage at Conveyor Entry and Exit for Eldoret Silos

Table 4.7
Data extract for Moi's Bridge Silos

S/No	% at Entry	% at Exit
1	3.0	6.0
2	4.5	4.5
3	2.9	3.0
4	3.5	3.8
5	1.6	2.1
6	2.0	2.5
7	4.0	4.9
8	3.0	4.3
9	3.2	4.2
10	4.9	7.2

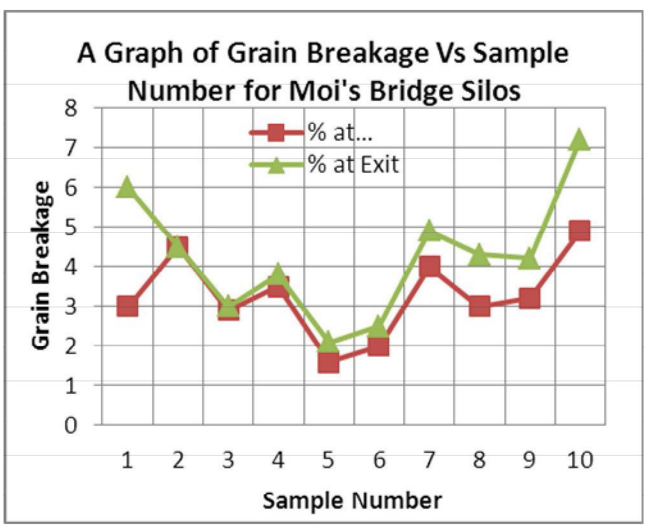

Fig. 4.2 A Graph showing % Grain Breakage at Conveyor Entry and Exit for Moi's Bridge Silos

Table 4.8
Data extract for Nairobi Silos

S/No	% at Entry	% at Exit
1	2.5	8.3
2	4.0	6.4
3	2.1	7.9
4	6.7	11.0
5	5.6	13.1
6	4.4	10.3
7	6.8	13.4
8	5.6	12.5
9	4.5	8.3
10	3.9	4.5

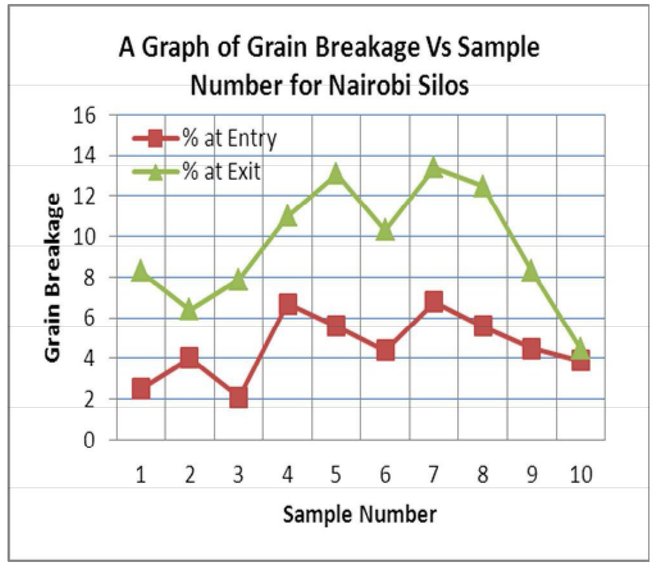

Fig. 4.3 A Graph Showing % Grain Breakage at Conveyor Entry and Exit for Nairobi Silos

4.3.1 Mean Grain Breakage

The mean grain breakage for the three stations where the tests were carried out is as follows:

i. <u>Mean breakage for Eldoret Silo Complex</u>

The mean grain breakage at the entry of all the ten drag chain conveyors which were selected for the study was as follows:

$$\frac{3.5+2.8+10.0+1.5+2.5+1.6+0.2+0.2+2.0+2.0}{10}=\frac{26.3}{10}$$

$= 2.63$

The average grain breakage at the exit of the conveyors was as follows:

$$\frac{7.8+6.4+12.0+2.5+2.9+3.0+2.2+3.1+3.0+7.0}{10}=\frac{49.9}{10}$$

$= 4.99$

ii. <u>Mean breakage for Moi's Bridge Silo Complex</u>

The average grain breakage at the entry was as follows

$$\frac{3.0+4.5+2.9+3.5+1.6+2.0+4.0+3.0+3.2+4.9}{10}=\frac{32.6}{10}$$

$= 3.26$

The average grain breakage at the exit of the conveyors was as follows

$$\frac{6.0+4.5+3.0+3.8+2.1+2.5+4.9+4.3+4.2+7.2}{10}=\frac{42.5}{10}$$
$$=4.25$$

iii. <u>Mean breakage for Nairobi Silo Complex</u>

The average grain breakage at entry was as follows:

$$\frac{2.5+3.0+2.1+6.7+5.6+9.4+6.8+5.6+4.5+3.9}{10}=\frac{50.1}{10}$$
$$=5.01$$

The average grain breakage at exit was as follows:

$$\frac{8.3+6.4+7.9+11.0+13.1+10.3+13.4+12.5+8.3+4.5}{10}$$
$$\frac{95.7}{10}=9.57$$

The mean grain breakage for the three stations are summarized in the table below

Table 4.9
Mean Grain Breakage for the Three Stations

Station	Mean at Entry	Mean at Exit
Eldoret Silos	2.63	4.99
Moi's Bridge Silos	3.26	4.25
Nairobi Silos	5.01	9.57

From table 4.9 above, the average grain breakage at entry for the three stations is obtained as follows

$$\frac{2.63+3.26+5.01}{3}=\frac{10.9}{3}$$
$$=3.63$$

and for exit

$$\frac{4.99+4.25+9.57}{3}=\frac{18.81}{3}$$
$$=6.27$$

The average difference between the entry and the exit is as follows:

$$6.27-3.63=2.64$$

From Table 4.4, a graph of grain breakage against distance from conveyor entry can be plotted as shown below

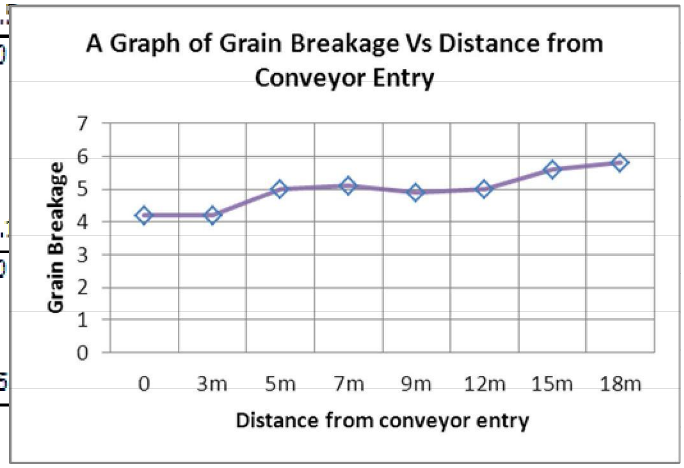

Fig. 4.4 A Graph of Grain Breakage against distance from conveyor entry for Conveyor loaded at full capacity

As per the data in Table 4.4 above, the difference between grain breakage at entry and at exit is obtained as follows

$$5.8-4.2=1.6$$

The test was then repeated with the conveyor loaded at ¼ of the conveyor's full capacity and the results recorded as shown in table 4.5 and a graph of grain breakage against distance from conveyor entry plotted as shown below.

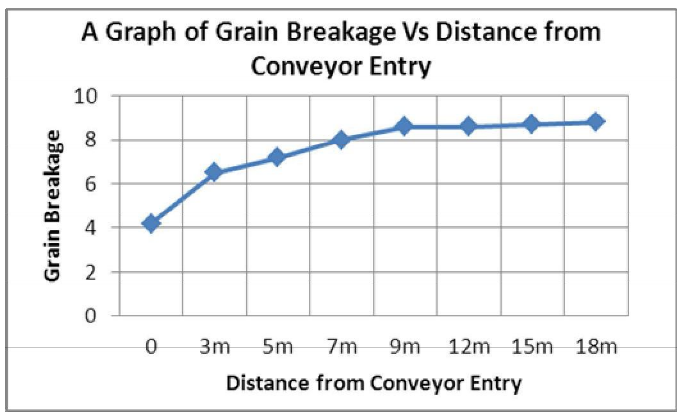

Fig. 4.5 A Graph of Grain Breakage against distance from conveyor entry for Conveyor Loaded at ¼ capacity

From Table 4.5 the difference between grain breakage at entry and exit is obtained as follows:

$$8.8-4.2=4.6$$

III. CONCLUSION

According to the data obtained from Eldoret and Moi's Bridge Silo Complex, the levels of grain breakage for the two stations are almost the same while that of Nairobi silos is much higher. This is because the two stations (Eldoret and Moi's Bridge) are mostly used to store maize grains that come direct from farmers while Nairobi silos is mostly used to store maize grains that have been transferred from other silos in order to create space. In this case, grain that is brought into the silos already has a higher level of broken grains as compared to the maize grains coming straight from the farmers.

Under normal operations, maize grains are stored in the silos at 12.5% moisture content. Due to moisture migration in the silos and changes in the external environment, the moisture contained in the grains fluctuates upwards or downwards slightly. It is evident from Tables 4.1, 4.2 and 4.3 that a reduction in the moisture contained in the grains results into an increase in brittleness hence increasing breakage susceptibility of the grains.

From the test carried out from the three stations, it was established that the drag chain conveyor can cause up to 2.63% grain breakage in maize grain. Considering the test carried out to establishing the effect of conveyor loading on grain breakage and which was carried out on one drag chain conveyor at one station, the results show grain breakage up to 1.62%. Since the value established from the tests carried out on several drag chain conveyors in different stations is 2.63%, the researcher concludes that a drag chain conveyor with steel flights causes grain breakage in maize within a range of between 1.62% and 2.63%.

By considering the grain breakage obtained by loading the conveyor at ¼ of full capacity i.e. 4.6%, the researcher concludes that under-loading of drag chain conveyors during normal operations can be very detrimental to the quality of maize grains.

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REFERENCES

[1] K.J. Hellevang, "Pneumatic Grain Conveyors" *Journal* of ASAE-850 No.58 (13), 1985.

[2] Kenya Bureau of Standards Grain Quality Manual (KSO1 – 43)

[3] C.W. Smith, J. Betrand, E.C.A Runge Corn: History, Technology and Production. Wiley, March 2004

[4] J.K. Mensa, "Effects of Drying Conditions on Impact Fracture Resistance on Selected Corn Varieties" Dept. of Agri. Eng., Ohio State University, Ohio 1976.

[5] M. Vanwormer, "Corn Damage and Its Effects on Feed Manufacturing" Journal of ASABE 30(6): pp.29-34, 1972.

[6] H.J. Roberts "Corn Damage and its effects on Dry Milling" Journal of ASABE 48 (13), pp.23-371972

[7] H.D. Almeida-Domínguez, G. G. Ordoñez-Durán, and N. G. Almeida, "Influence of Kernel Damage on Corn Nutrients Composition, Dry Matter Losses and Processability during Alkaline Cooking" Journal of Cereal chem.Vol.75 No.1 pp.124-128, 1998

[8] G.M. Hamilton, "Discoloration and Stress Cracking of White Corn as Affected by Drying" Journal of ASABE 46(2), pp. 30-90, 1972.

[9] J.M. Boac, "Quality Changes, Dust Generation, and Commingling During Grain Elevator Handling" Dept. of Biol. and Agric. Eng., Kansas State University, Manhattan 2010.

[10] L.D. Sands and Hall "Damage to Shelled Corn during Transport in a Screw Conveyor" Journal of ASAE 14(3), pp.584-585, 589 1971.

[11] D. E Fiscus, G. H. Foster, and H. H. Kaufman. "Physical damage of Grain caused by various Handling Techniques" *Transactions of the ASAE* 14(3): 480-485, 491, and 1971.

[12] G. H Foster and L.E. Holman, "Grain Breakage Caused by Commercial Handling Method" USDA, Research Services. Marketing Research Report. No. 968, 1973.

[13] D.L Keller, "Corn Kernel Damage due to High-Velocity Impact" Journal of ASAE 15(2), pp.330-332, 1972

[14] K. D Baker, R. L. Stroshine, K. J. Magee, G. H. Foster, and R. B. Jacko.. "Grain Damage and Dust Generation in a Pressure Pneumatic Conveying System" Journal of ASAE 29(2): pp.840-847, 1986.

[15] D.B Hastie, "Belt Conveyor Transfer: Quantifying and Modeling Mechanisms of Particle Flow" 2010.

[16] G.L Kline, "Damage to Corn during Harvest and Drying" Journal of ASABE 45(3) pp.79-82, 1972.

[17] H. H Converse and S. R Eckhoff, "Corn Dust Emissions with Repeated Elevator Transfers after Selected Drying Treatment" *Transactions of the ASAE* 32(6): 2103-2107, 1989.