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   STATEMENT OF THE PROBLEM

   OBJECTIVES

   HYPOTHESES

   RESEARCH METHODOLOGY

   RESULTS & DISCUSSION

   FINDINGS

   RECOMMENDATIONS/SUGGESTIONS

   CONCLUSIONS

   SCOPE FOR FURTHER RESEARCH

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   APPENDIX/ANNEXURE

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CONTRIBUTIONS TO BOOKS

- Sharma T., Kwatra, G. (2008) Effectiveness of Social Advertising: A Study of Selected Campaigns, Corporate Social Responsibility, Edited by David Crowther & Nicholas Capaldi, Ashgate Research Companion to Corporate Social Responsibility, Chapter 15, pp 287-303.

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- Schemenner, R.W., Huber, J.C. and Cook, R.L. (1987), "Geographic Differences and the Location of New Manufacturing Facilities," Journal of Urban Economics, Vol. 21, No. 1, pp. 83-104.

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- Kumar S. (2011): "Customer Value: A Comparative Study of Rural and Urban Customers," Thesis, KurukshetraUniversity, Kurukshetra.

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- Garg, Bhavet (2011): Towards a New Natural Gas Policy, Political Weekly, Viewed on January 01, 2012 http://epw.in/user/viewabstract.jsp

EXPERIMENTAL INVESTIGATION ABOUT INFLUENCES OF PROCESSING PARAMETERS IN PLASTIC EXTRUSION PROCESS

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ABSTRACT

The objective of this paper is to find the root causes for nonconformity occurrences in plastic extrusion process. Data has been taken on the main causes for products defect and studied the relative contribution of plastic extrusion process parameters .To achieve this four sample products were selected which are pipe (HDPE1 Ø 50mm, Plain pipe Ø 25mm), conduit (F/C Ø 16mm) and poly products (F/B 8cm/220μm). Four independent process parameters were investigated, namely vacuum pressure, take-off speed, screw speed and temperature were considered for DOE. The defects identified are such as surface roughness and scratches, bulging, sink marks, uneven wall thickness, uneven film Width, dimensional variation, centering problem, tears and marks. On this particular case study, by using the principle of Taguchi's loss function, loss function was calculated and compared with the quality loss before applying of DOE. From this it was understood that, using Taguchi's method of design of experiment the quality loss because of performance deviation improves by about 85.31% for the selected products.

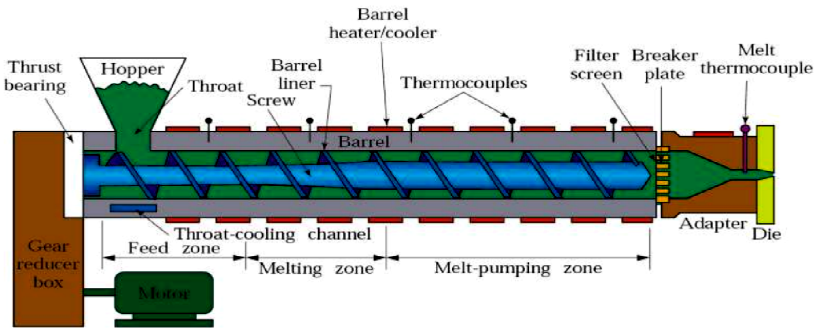
KEYWORDS
Plastic Extrusion, Nonconformity, Influence Factors, Design of Experiment.

1. INTRODUCTION
Polymers have many advantages as they are light in weight, provide design flexibility, offer electrical insulation, and have relatively low overall and manufacturing cost. Hence the advantages of synthetic polymers are over competent than other materials like metals, it is reasonable to predict that polymers will take an even greater allocation of the total material market in the future [1].

It is estimated that the material used in extrusion can account for 50%-70% of total costs, and if the costs of labour are included, these altogether can vary within an order of 60%-80% of total costs. Any technique that can reduce labour costs, minimize material wastage and attain the required quality is undoubtedly an important factor for consideration [2].

Bahir Dar plastic factory PLC is engaged in production and sales of plastic products such as conduits, PVC, dripper elements, HDPE, plane pipe, FB (film bloom) etc. It manufactures products by injection molding, blow molding and extrusion process. However, the factory produces enormous amounts of nonconformities; quantitatively the total rejection was from 14,346.584kg to 65,426.78kg per month on the year of 2010/11. The most important polymer processing operation in the factory is extrusion and the most popular materials used in the factory are PVC, HDPE, LDPE and LLDPE. Extrusion is material intensive. This process involves the following sequence; heating and melting the polymer, pumping the polymer to the shaping unit, forming the melt in to the required shape and dimensions, cooling and solidification (Fig.1).

FIG. 1: SCHEMATIC ILLUSTRATION OF A TYPICAL SINGLE-SCREW EXTRUDER



Good quality of extrusion is ideally carried out under the design condition of constant screw rotational speed and temperature and uniform composition. Poor extradite quality for a given designed extruder can be related to the inappropriate setting of processing conditions [3].

2. LITERATURE REVIEW

To show how the inappropriate setting of processing conditions affected the product quality, Maddock [4] in his work described the case of quality requirement for the extrusion of 1.0 mm thick film. Due to temperature difference the viscosity is affected and the viscosity variations act to produce pressure changes and so caused large thickness variations. High extrusion rates and good extrusion quality are often two extremes and thus incompatible. Tadmor and Klein [5] classified bad mixing of the components forming the product can result in bad appearance and a non-uniform product. Non-uniformity in products can lead to weakness of mechanical strength. Poor extrusion quality for a given extruder is frequently related to random difference of temperature, pressure, and flow rate. Dowd [6] and young [7] reported that the product properties are depends on the extrudate temperature. Fenner, et al. [8] also stated that screw cooling reduces throughput, thus eliminating these fluctuations without cooling the screw will allow these extruders to achieve a higher level of productivity. And extrusion experts identify five factors that limit product throughput and quality: power or screw speed, temperature, feed, vacuum pressure, and downstream processing [9].

3. THE PLANNING OF THE EXPERIMENT

In this case design of experiment was applied to study of influence of the factors (process parameters) in plastic extrusion process, which were considered to be the main causes for defect of products. The products selected were pipe (HDPE1 Ø 50mm, Plain pipe Ø 25mm), conduit (F/C Ø 16mm) and poly products (F/B 8cm/220µm). Sample of the selected types of products are shown in Fig. 2.

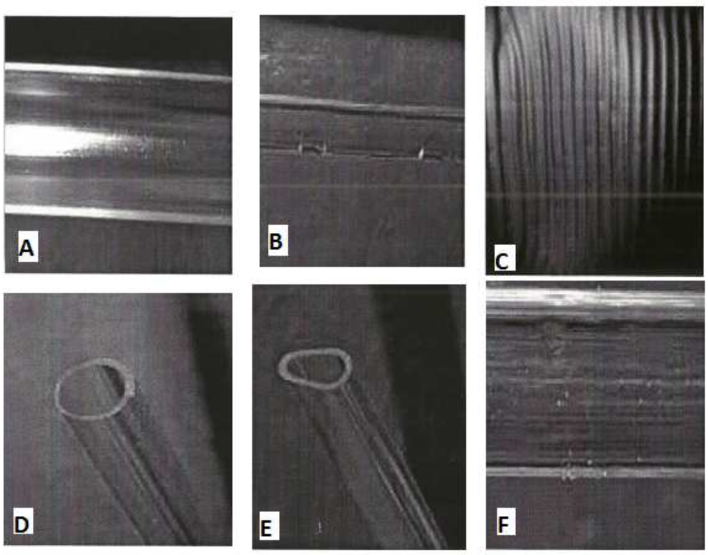
FIG. 2: THE SAMPLE PRODUCTS

3.1 DEFECTS IN EXTRUSION PROCESS

Defect is any form of deviation of the product's characteristic from the specification set up by the manufacturing process. It can be caused by a single source or the cumulative effect of several factors, which may arise at any stage of the processing. The Common failure or defects which are normally occurring in plastic extrusion process are due to three main causes are part and mold design, material selection, and processing. In many cases, the failures occur during the processing and these failures causes some defects that can be found in extruded parts such as: warpage, sink mark, residual stress, air trap, weld line, sink marks, low gloss, uneven surface gloss, spotted surface, rough surface, extruder surging, thickness variation, uneven wall thickness, diameter variation, centering problem as shown in fig. 2. In extrusion products, defects due to processing include, poor understanding of the processing method, use of inadequate or old machines, lack of trained staff, machine break down, and inappropriate working environments.

A Surface roughness
B Marks
C Bulging
D Dimensional variation
E Out of round
F Sink marks

FIG. 3: OBSERVED DEFECTS

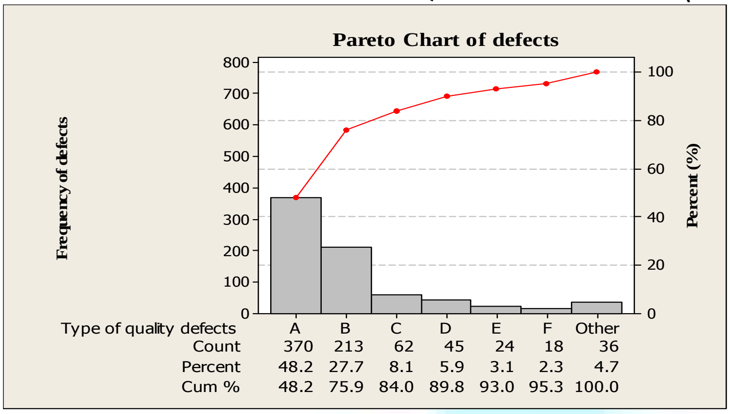


Here data was collected from reported data and from personal observation of the case factory in this particular section, the collected data are presented, analyzed and corrective actions will be selected, suggested and developed.

3.2 INDENTIFY MAJOR DEFECT OF THE PRODUCTS

The total defects occurring on the specific product type (categories) with in a six month was recorded and this is analyzed using the Pareto chart to know the most frequently occurring. The detailed analysis of this major extrusion defect for a specific product is made very precisely.

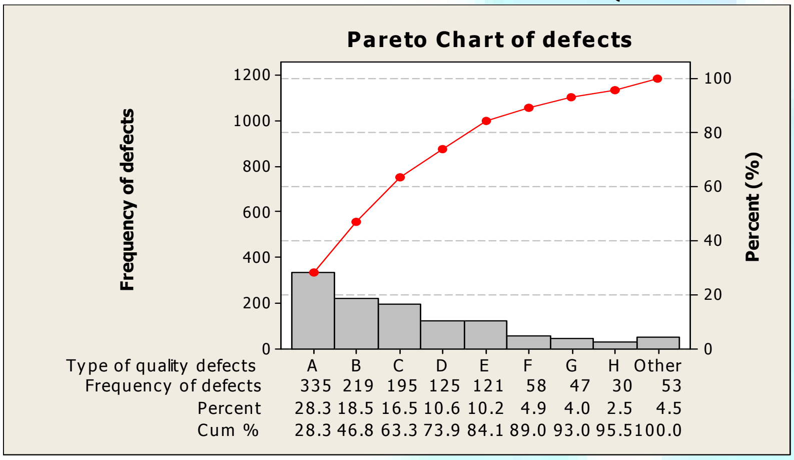
FIGURE 4. PARETO CHART FOR DEFECTS HAPPENING FREQUENTLY IN POLY PRODUCTS (FILM BLOOM, POLY BAG, POLY TUBULAR, POLY CARRIER)



Type of quality defects
Uneven Width (A)
Thickness Variation (B)
Length Variation (C)
Shrinkage/Folding (D)
Chatter marks (E)
Scratching (F)

The highest frequency percentage is 75.9% that indicates the defects occurring on poly products are thickness variation and width variation. So that, the company as well as the researcher should give emphasis on these Quality defects of Poly products and should identify appropriate raw material, root causes and optimal process parameters to improve output quality of poly products in achieving this, the company will profitable, competent and order winners.

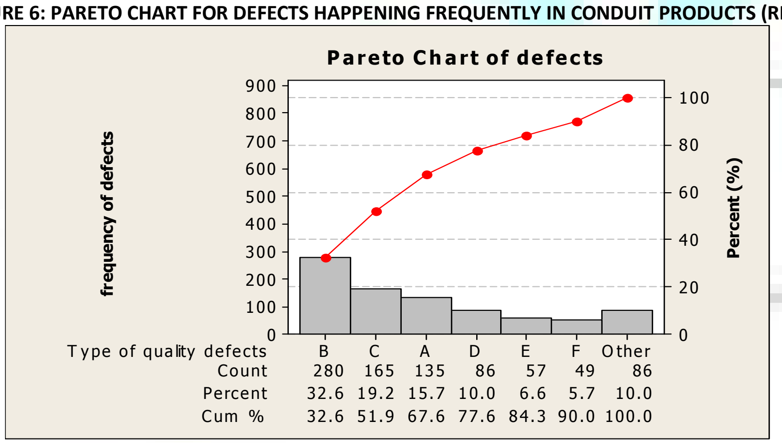
FIGURE 5. PARETO CHART FOR DEFECTS HAPPENING FREQUENTLY IN PIPE PRODUCTS(IDP, PVC, HDPE, IR AND LDPE)



TYPE OF QUALITY DEFECTS	
Uneven Wall thickness (A)	
Centering problem(off-center) (B)	
Diameter variation (C)	
Sink marks(D)	
Scratching (E)	
Discontinuity (F)	
bend(G)	
Poor surface finishing (H)	

The highest frequency percentage is 63.3% that indicates the defects occurring on pipe products are wall thickness variation, centering problems (off-centering) and diameter variation. In this case great attention is given for those defects in order to minimize those defects.

FIGURE 6: PARETO CHART FOR DEFECTS HAPPENING FREQUENTLY IN CONDUIT PRODUCTS (RIGID CONDUIT, FLEXIBLE CONDUIT, DRIPPER ELEMENT)



Type of quality defects
Uneven Wall thickness (A)
Centering problem (off-center) (B)
Diameter variation (C)
Marks & Sink marks (D)
Poor surface finishing (E)
Tearing/discontinuity (F)

The highest frequency percentage is 67.6% that indicates the defects occurring on Conduit products are centering problems (off-centering), diameter variation, and uneven wall thickness.

It can be seen from the above table and bar chart that the following Table .1 as the summery of these data for the frequency of defects occurred for the last six months.

TABLE 1: SUMMARIZED FOR FREQUENTLY OCCURRING DEFECTS OF THE COMPANY'S PRODUCTS

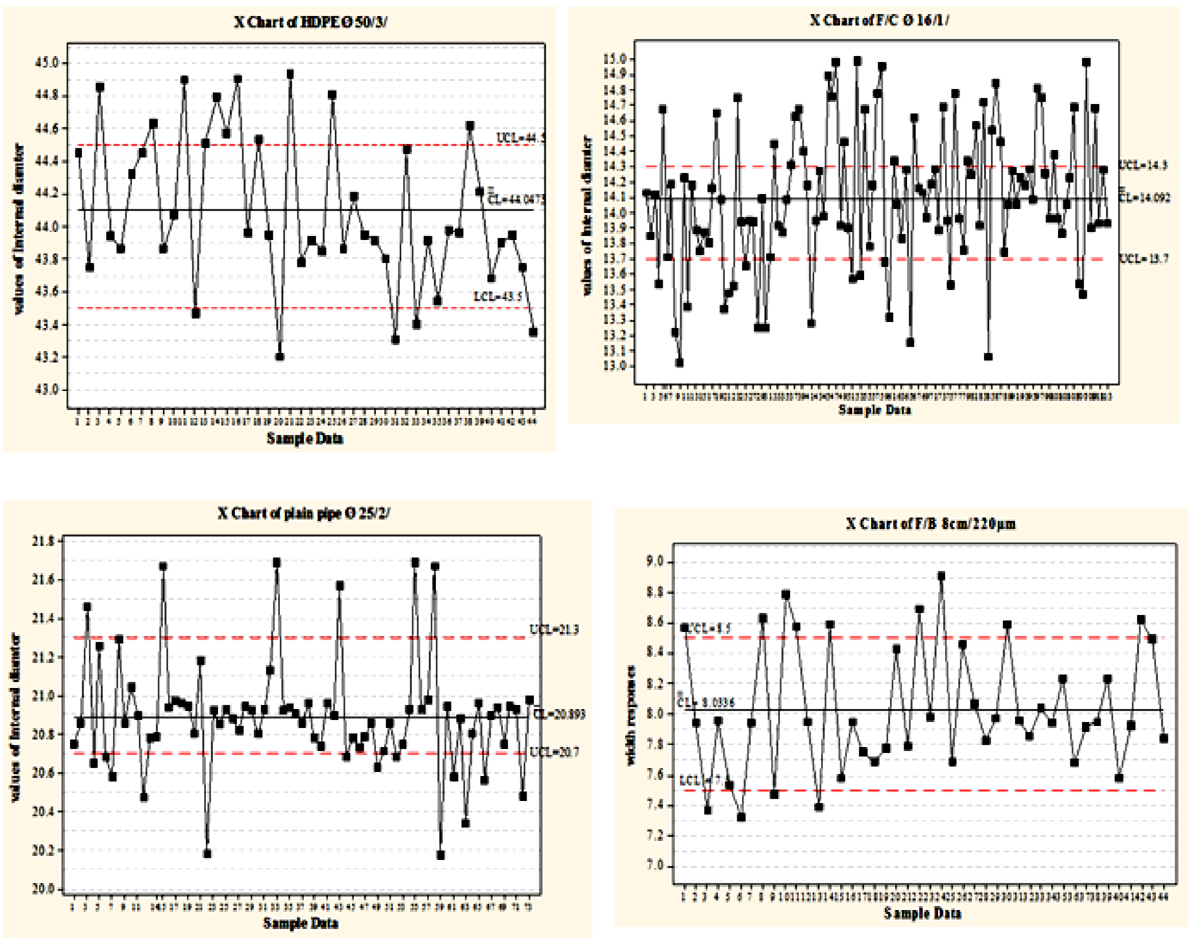
Product type	Frequently occurring defects
Poly products	Uneven Width Thickness Variation Length Variation
Pipe products	Uneven wall thickness Centering problems Diameter variation
Conduits	**Centering problems** **Diameter variation** **Uneven wall thickness**

From those defects when we see their level of impact on customer satisfaction and increasing cost of production, diameter variation and wall thickness variation are the main concerns of the company. As a result, attention has been given for this product category in reducing diameter variation for F/C Ø 16mm (flexible conduits dia16/1.0/16bar) is chosen as a case because this product is produced frequently..

3.3 X - CHART ANALYSIS OF THE SELECTED PRODUCTS

From the data collected of each product of our case study, X - Chart analysis is developed for some samples in order to show clearly whether the production process is out of limit or control. The data collected for each product was given below with X –Chart form.

FIGURE.7: X – CHART OF HDPE1 Ø 50mm, F/C Ø 16mm, PLAIN PIPE ϕ25 mm PRODUCTS, AND F/B 8cm/220µm PRODUCT RESPECTIVELY FROM LEFT TO RIGHT



4. ANALYSIS OF QUALITY LOSS FOR DETERMINING THE INFLUENCE OF PROCESS PARAMETERS

From the results of the Pareto data analysis and X – Chart from the above sections, type and frequency of defects that occurred in those products were identified. Taguchi's loss function has been functional to calculate the quality loss of the chosen products.

4.1. SELECTION OF PROCESS PARAMETERS FOR THE PRODUCTS

The optimum operating condition for different extrudates is varied so as to get quality product. Based on the above to minimize the selected defects, the main process parameters should be selected and those are residence time, temperature zones, screw speed, vacuum pressure and cooling time. In this case, this study will give emphasis to vacuum pressure, take-off speed, screw speed and temperature zones settings for getting quality products, and setting other parameters constant.

High density polyethylene Pipe (HDPE1 Ø 50/3.0/ 10bar PE- 100) -The Process parameters used in the experiment for this product are vacuum pressure 1, take-off speed 2 and Temperature 3 Temperature 4, Temperature 5 and Temperature 6 Temperature7 Temperature 8 are the process parameters in this case the response value or target value is internal diameter & uneven wall thickness.

Plain pipe (IR Ø 25/1.8/16bar PE-100) - The process parameters used in the experiment for this product are vacuum pressure 1, take-off speed 2 Temperature 3, Temperature 4, Temperature 5 and Temperature 6 while the performance measures are internal diameter wall thickness.

Flexible conduit (F/C Ø 16mm/1.0/) -The process parameters used in the experiment for this product are vacuum pressure 1, take-off speed 2 Temperature 3, Temperature 4 and Temperature 5 hence the performance value (response value) are internal diameter& uneven wall thickness.

Film Bloom 8cm/220µm (F/B 8cm/220µm - LLDPE) - Variables and Control factors used in the experiment for this product are speed 1, take-off speed 2, and Temperature 3, Temperature 4, Temperature 5, Temperature 6, Temperature 7, and Temperature 8 while width is the performance measure (response value) for this product.

4.2. QUALITY LOSS CALCULATION

For this paper, Nominal-The-Best (NTB) quality loss measurable characteristic has been used for analysis and decision confirmation for the optimization the critical process parameters that influence the campiness product quality. Here to calculate the loss function for the selected product using the theory of Taguchi's loss function the value of L (failure cost) used in this calculation is taken from the following data.

TABLE 2: SIX MONTH PRODUCTION DETAILS

Types of products	Six month production(Kg)	Mass of a product per piece (Kg)	Cost of raw material (birr/Kg)	Production cost (birr)
HDPE PIPE Ø50 mm	163,407.00	0.458	35.0849	12.551
Plain pipe Ø25 mm	89,652.00	0.139	35.0849	4.3232
Flexile conduit Ø16mm	27,544.56	0.1816	10.36	2.498
Film Bloom 8cm/220µm	105,476.00	1.0	33.5	24.78

NB: 1Pc of conduit product is cut into 3m.

This company loses a lot in each month and the total cost could be multiplied with the current market of Ethiopia shortly illustrated on Table 4.2. The general formula used to calculate the failure cost for all selected products is;

$$\text{Failure cost} = \text{production cost (birr/pc)} - (\text{mass of aproduct (Kg/pc)} * \%\ \text{recyclable} * \text{cost of raw material (birr/Kg)})$$

TABLE 3: FAILURE COST OF SAMPLE PRODUCTS PER A UNIT OR WEIGHT

Product	Failure Cost
Film Bloom 8cm/220µm	9.728birr/kg
Flexible Conduit Ø16mm	1.21 birr/pc
Plain Pipe Ø25 mm	1.53birr/pc
HDPE Pipe Ø50 mm	2.484 birr/pc

To calculate the quality loss some assumptions should be set and they are; 1. Failure cost = production cost - cost saved by recycling scraps and 2. Maximum loss was occur at the two tolerance

SD = Standard deviation, µ = mean value of samples, m = target value, TL = tolerance limit, L = failure cost of the product.

4.2.1. HIGH DENSITY POLYETHYLENE PIPE (HDPE1 Ø 50/3.0/ 10bar PE-100)

SD= 0.265, µ=44.0473mm, m=44mm, TL=44±0.5mm and L=2.484 birr (data taken) (Failure costs of the selected products, taking into consideration there is recyclable scraps) so this loss is calculated as the following, for a single product.

$$L(y) = k(y-m)^2 \Rightarrow 2.484 = k(44.5-44)^2 \Rightarrow k = 9.936$$

Average quality loss for this specific product is,

$$L = k(s^2 + (\mu - m))^2 \Rightarrow L = 9.936(0.265^2 + (44.0473-44)^2) \Rightarrow L = 0.7199\text{birr/pc}$$

4.2.2. F/C Ø 16/1.0/16bar

SD = 0.1624, µ=14.092mm, m=14mm, TL=14±0.3mm and L=1.21birr. Depending on the above values the failure costs of the product (per single) was calculated as,

$$L(y) = k(y-m)^2 \Rightarrow 1.21 = k(14.3-14)^2 \Rightarrow k = 13.44$$

The average quality loss for this product is,

$$L = k(s^2 + (\mu - m))^2 \Rightarrow L = 13.44(0.1624^2 + (14.092-14))^2 \Rightarrow L = 0.468\text{ birr/pc}$$

4.2.3. PLAIN PIPE dia25/2/ 16bar PE-100)

SD =0.1932, µ=20.893mm, m=21mm, L=1.53birr, TL=21±0.3mm

$$L(y) = k(y-m)^2 \Rightarrow 1.53 = k(21.3-21)^2 \quad k = 17.0$$

Therefore, the average quality loss function for this product is,

$$L = k(s^2 + (\mu - m))^2 \Rightarrow L = 17.0(0.1932^2 + (20.893-21)^2) \Rightarrow = 0.8294\text{birr/pc}$$

4.2.4. F/B 8cm/220µm

SD =0.1415, µ=8.0336cm, m=8cm, L= 9.728birr, TL=8cm±0.5cm

$$L(y) = k(y-m)^2 \Rightarrow 9.728 = k(8.5-8.0)^2 \Rightarrow k = 38.91$$

Therefore, the average quality loss function for this type of product is,

$$L = k(s^2 + (\mu - m))^2 \Rightarrow L = 38.91(0.1415^2 + (8.0752-8.0)^2) \Rightarrow L = 0.999\text{birr/kg}$$

4.3 DESIGN OF EXPERIMENT

The effect of many different parameters on the performance characteristic in a condensed set of experiments can be examined by using the orthogonal array experimental design proposed by Taguchi (DOE). Once the parameters affecting a process that can be controlled have been determined, the levels at which these parameters should be varied must be determined. The process parameters considered in DOE of the case company's production process were vacuum pressure, Take-off speed, screw speed and temperature but here we have to give more emphasis to temperature.

TABLE 4: PARAMETERS USED FOR CONDUCTING THE EXPERIMENT (DOE)

High density polyethylene Pipe (HDPE dia50/3/ 10bar PE- 100)					**Film Bloom 8cm/220µm (F/B 8cm/220µm)**			
Control factors (Temperature zones in C ,vacuum pressure in bar and take-off speed in m/min)	Levels				Control factors (Screw speed in KHZ , Temperature zones in C and take-off speed in m/min)	Levels		
	1	2	3	4		1	2	3
pressure 1	-50.5	*-55.0*	-58.5	*-62.5*	Screw speed 1	56	*60*	*65*
take-off speed 2	1.6	1.8	2.0	2.4	take-off speed 2	16	*18*	*20*
Temperature 3	125	130	135	140	Temperature 3	70	*80*	*85*
Temperature 4	130	135	140	145	Temperature 4	110	*114*	*121*
Temperature 5	140	145	150	155	Temperature 5	114	*121*	*125*
Temperature 6	155	160	165	165	Temperature 6	22	*124*	*130*
Temperature 7	155	160	*165*	*170*	Temperature 7	125	*130*	*133*
Temperature 8	160	165	170	175	Temperature 8	128	*130*	*135*
Response variable: Internal diameter & wall thickness					Response variable: Width			

TABLE 5: PARAMETERS USED FOR CONDUCTING THE EXPERIMENT (DOE)

Flexible conduit (F/C Ø 16mm/1.0/)					Plain pipe (IR Ø 25/2.0/16bar PE-100)				
Control factors (Temperature zones in C ,vacuum pressure in bar and take-off speed in m/min)	Levels				Control factors (Screw speed , Temperature zones and take-off speed)	Levels			
	1	2	3	4		1	2	3	4
pressure 1	-3.0	*-5.0*	*-7.0*	*-8.0*	pressure 1	-5.5	*-6.5*	*-7.5*	*-9.0*
take-off speed 2	10.5	*12.0*	*14.0*	*16.0*	take-off speed 2	5.0	*6.0*	*7.5*	*8.5*
Temperature 3	150	160	165	170	Temperature 3	110	115	120	125
Temperature 4	150	155	160	170	Temperature 4	125	130	135	140
Temperature 5	130	140	145	150	Temperature 5	125	130	140	145
					Temperature 6	130	145	150	155
Response variable: internal diameter & wall thickness					Response variable: internal diameter & wall thickness				

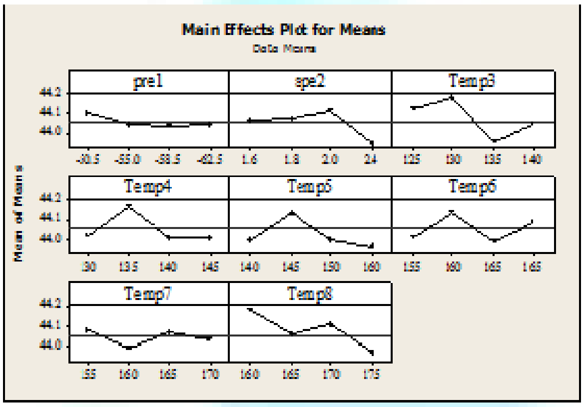
From the data obtained from the experiments for each selected products, mean response and signal to noise ratio (S/N) analysis were done. So that Corresponding S/N ratio equation for nominal the best (NTB) is given as:

$$SN = 10\log\left(\frac{(ybar)^2}{s^2}\right)$$

5. RESULT AND DISCUSSION

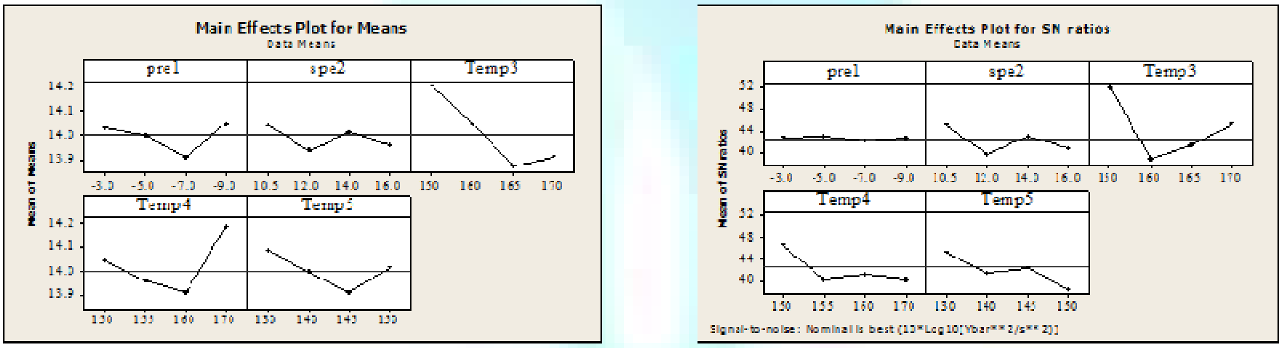
5.1. HIGH DENSITY POLYETHYLENE PIPE (HDPE dia50/3/ 10bar PE- 100)

FIG. 8: HIGH DENSITY POLYETHYLENE PIPE



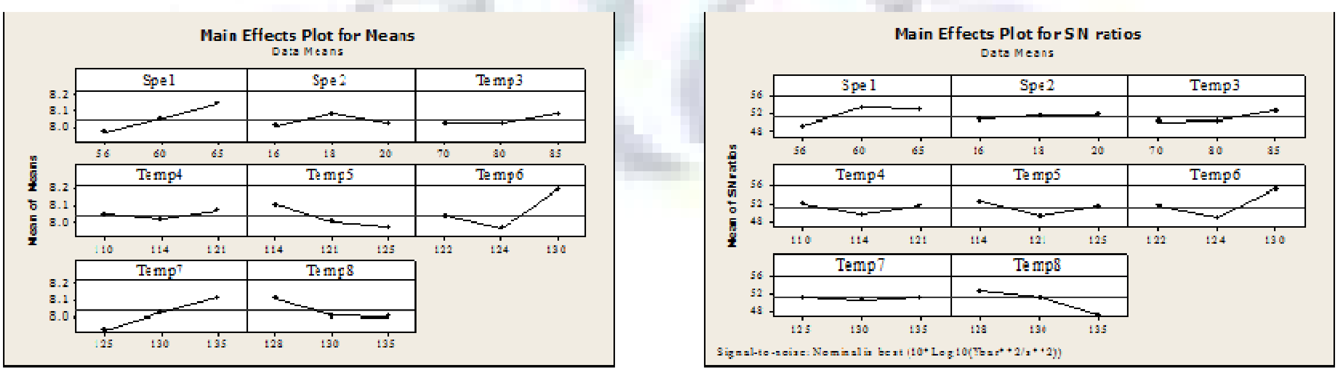
5.2. FLEXIBLE CONDUIT (F/C Ø 16mm/1.0/)

FIG. 9: FLEXIBLE CONDUIT



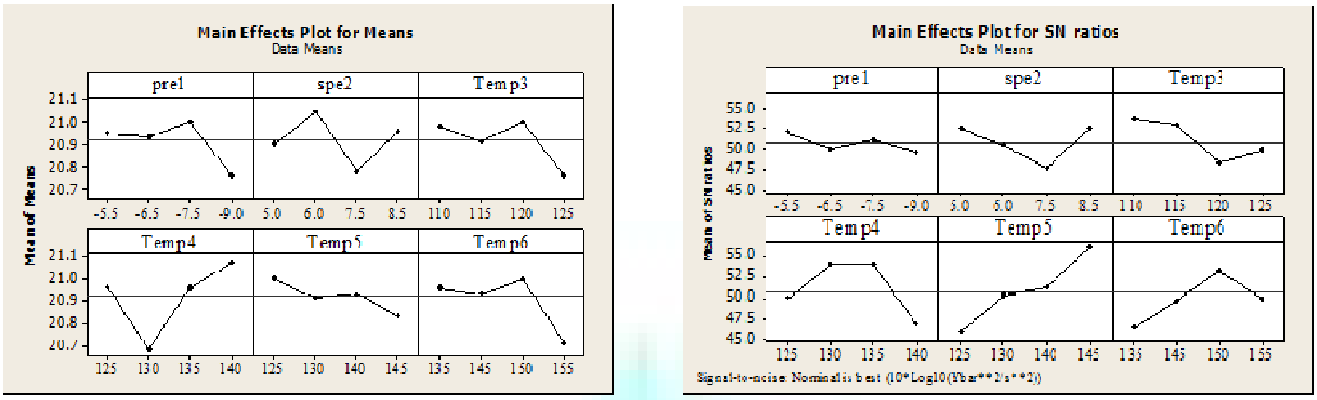
5.3. FILM BLOOM 8cm/220µm (F/B 8cm/220µm)

FIG. 10: FILM BLOOM



5.4. PLAIN PIPE (IR Ø 25/2.0/16bar PE-100)

FIG.11: PLAIN PIPE



The Summary of factor settings selected using the design of experiment is shown in the following table.

TABLE 6: SUMMARY OF FACTOR SETTINGS SELECTED USING THE DESIGN OF EXPERIMENT

1. HDPE1 Ø 50/3.0/ 10bar PE -100				2. F/B 8cm/220µm			
Controllable factors	Level selected	Value of the level	Rank of affecting the response	Controllable factors	Level selected	Value of the level	Rank of affecting the mean response
Vacuum pressure 1	1	-50.5	8	Screw speed 1	2	60	3
Take-off speed 2	2	1.8	3	Take off Speed 2	2	18	6
Temperature 3	4	140	1	Temperature 3	3	85	2
Temperature 4	4	145	5	Temperature 4	1	110	8
Temperature 5	3	150	4	Temperature 5	1	114	4
Temperature 6	1	155	6	Temperature 6	1	122	1
Temperature 7	2	160	7	Temperature 7	2	130	7
Temperature 8	2	165	2	Temperature 8	2	130	5

TABLE 7: SUMMARY OF FACTOR SETTINGS SELECTED USING THE DESIGN OF EXPERIMENT

3. F/C Ø 16mm/1.0/				4. Plain pipe Ø 25/2.0/16bar PE-100		
Controllable factors	Level selected	Value of the level	Rank of affecting the mean response	Level selected	Value of the level	Rank of affecting the mean response
Vacuum pressure 1	2	-3.0	3	1	-5.5	4
Take-off speed 2	3	14.0	4	1	5.0	5
Temperature 3	3	165	1	3	120	1
Temperature 4	1	150	2	3	135	3
Temperature 5	2	130	5	2	140	6
Temperature 6				3	150	2

5.5. FORECASTING OF RESPONSE RECOMMENDED VALUES OF SELECTED PRODUCTS

TABLE 8: THE PREDICTED VALUES AND ACTUAL MEAN VALUES OF THE PRODUCTS

Product type	Predicted values			Target value (mm)	Actual mean value (mm)	Predicted mean value(mm)
	Mean		Standard deviation			
	Diameter/Width	Wall thickness	Diameter/Width			
HDPE1 Ø 50mm	43.9766	accepted	0.120385	44.00	44.0473	43.9766
F/B 8cm/ 220µm	8.0436	accepted	0.0235702	80	80.752	80.436
F/C Ø 16mm	13.9583	accepted	0.064872	14.00	14.092	13.9583
Plain pipe Ø 25mm	20.9642	accepted	0.065068	21.00	20.893	20.9642

Here with the help of the forecasted (predicted) value and the actual average value of the recorded data production of the company (X –Chart analysis of the products) we compare these two values as the table 9.

Total average loss

HDPE Ø 50mm = 0.1494 Birr/piece

F/B 8cm/220µm = 0.0956Birr/piece

F/C Ø 16mm = 0.0799 Birrr/piece

Plain pipe Ø 25mm = 0.0943 Birr/piece

To summarize the quality loss function after and before the application of Taguchi's method of design of experiment (DOE) the following table. 9 show briefly.

TABLE 9: COMPARISON OF QUALITY LOSS BEFORE AND AFTER EXPERIMENTAL ANALYSIS

Type of product	Loss before experiment/Pc of product (birr)	Loss after experiment /pc of product (birr)	Percentage Improvement (%)
HDPE1 Ø 50mm	0.7199	0.1494	79.25
F/B 8cm/220µm	0.999	0.0956	90.43
F/C Ø 16mm	0.468	0.0799	82.93
Plain pipe Ø 25mm	0.8292	0.0943	88.63

From this table that is the percentage of loss improvement for the selected products was dramatically improved through the application of Taguchi's method of design of experiment.

CONCLUSION

From the result of the X-chart analysis all of the production process of the product is out of control, so that improvement should be made by minimizing its causes for the best target values. And it can be observed on cause and effect diagram that the root causes of these quality problems (defects) are inappropriate setting of operational parameters. By the application of Taguchi's method of design of experiment the percentage of loss has shown a dramatic improvement, as predicted, for the selected products. These process parameters are recommended. Therefore, as a consequence of processing the statistic data obtained, the influence of four process parameters is determined on the Extrusion processes, (vacuum pressure, take-off speed, screw speed and temperature). The greatest importance belongs to temperature in general for all products.

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