Optimization of Integrated Batch Mixing and Continuous Flow in Glass Tube & Fluorescent Lamp

Mina Faragallah[1] and A. A. Elimam[2]
[1]*Continuous Improvement Engineer, Mondeléz Egypt, 10th Ramadan, Egypt*
[2]*Mechanical Engineering Department, The American University in Cairo, New Cairo, Egypt*

Keywords: Production Planning, Continuous Production, Batch Mixing, Linear Programming.

Abstract: This paper deals with production planning of in-series continuous flow, and discrete production plants. The work is applied to glass and fluorescent lamp industry, where raw materials are mixed in batches, charged to a continuous furnace to produce glass tubes, and then assembled into discrete lamps. A non-linear programming model was formulated from the raw material mixing stage till the production of fluorescent lamps. Using the model, the amount of each raw material can be obtained at minimum cost, while satisfying the desired properties of the produced glass. The model also provides the optimum lamp production amounts, inventory levels, and the glass pull rate from the furnace, which determines the production amounts of glass tubes. An important factor in the continuous flow process is the amount of broken glass (cullet) added in the furnace, which has an impact of raw material cost and natural gas consumption. In order to solve the model, separable programming methods and linear approximations were used to transform the non-linear terms. Results are validated versus actual production data from local Glass & Lamp factories, and the model proved to be an efficient tool of integrating the whole process at minimum cost.

1 INTRODUCTION

The sequence of manufacturing a fluorescent lamp starts with the production of light bulb. Glass tube production is considered a continuous process and it is followed by a discrete assembling process. The production of glass bulb starts with mixing of glass basic material. Silica sand, dolomite, limestone, potash feldspar, soda ash, borax, carbon, sodium sulphate, magnesium, and alumina are the major raw materials used to form the glass batch. The batch is then charged to the furnace at 1475ºC. In order to shape glass into tubes, the molten glass flow over a rotating hollow cylinder to take the shape and a flow of air is blown inside the hollow cylinder. Then, the formed tubes are pulled using conveyors, cooled down at room temperature, and cut according to the desired length. The edges are modified to facilitate the assembly process. The tubes are then coated with the phosphorous coating, and the tungsten filament are assembled to the coated bulb. After that the bulb goes through exhausting, in which the tubes are vacuumed, the inert gas and the mercury drop are inserted inside the bulb and then, the bulb is sealed. End-Caps are then added to the edges of the sealed bulb and finally the lamp is tested before packaging.

2 PROBLEM DEFINITION

In such an industry, the production processes are dependent to one another. Any stoppages at one of the processes due to breakdowns or material shortages will affect the whole operation. For example, when the assembly process stops, the production of glass tubes should stop as well. However, glass production is a continuous flow operation where the production line runs 24 hours a day over 7 days of the week. The furnace is the crucial component at the whole production line where any change in the production quantity for example should be introduced gradually because of the considerable setup cost. Therefore, furnace shutdown can cause significant loss to the factory. In case of low demand and in order to avoid shutting-down the furnace, the production quantity is reduced to the minimum, leading to lower utilization. In addition, the unit cost of the glass tube increases due

Faragallah M. and A. Elimam A.
Optimization of Integrated Batch Mixing and Continuous Flow in Glass Tube Fluorescent Lamp.
DOI: 10.5220/0006192401190127
In *Proceedings of the 6th International Conference on Operations Research and Enterprise Systems (ICORES 2017)*, pages 119-127
ISBN: 978-989-758-218-9

to the reduction in production quantities. Therefore, decisions should be taken with the objective to minimize the total variable cost of the integrated operations. The variable costs are raw material, energy, inventory, and crushing cost. Several factors should be considered in order to achieve such an objective. The variables, representing these factors, are the amount of each raw material inside the glass batch, the Glass Pull Rate (P), the percentage of glass culets added to the batch (MG), the thickness of the glass tube, the inventory level in various stages (straight tube, shaped tube, and fluorescent lamp), and the scheduled scrap quantity. Given these variables, the following variety of actions could be pursued in order to minimize waste

- Given the chemical composition and the cost of each raw material, the factory has to decide upon the weight percentage of each raw material inside the batch to minimize the raw material cost without affecting the basic characteristics of the final product, such as the glass density, and the thermal expansion coefficient.
- Increasing the glass cullet percentage in the batch reduces the raw material, so the raw material cost is reduced. On the other side, the amount of glass cullet required increases, so the amount of glass tubes crushed increases.
- Also, reduction in P cause reduction in the production quantity. However, this will increase the residence time inside the furnace causing changes in the chemical composition of glass inside the furnace. Therefore, change in P should be minimized.
- The factory has to make a decision on the inventory level and on the amount at each stage, straight tube, end-formed tube, fluorescent lamp based on the inventory cost at each level and the storage limits.
- Moreover, the factory might decide upon crashing some of the glass tubes if the inventory level increases.

3 LITERATURE REVIEW

The problem mentioned above have been discussed in the literature under two major research areas, namely: raw material mixing to form the final product and production planning.

Several scholars tackled the raw material glass mixing to reach an efficient batch calculation. Khaimovich and Subbotin (2005) have developed an automated program for this batch calculation. The aim of the program is to decide upon the amount of each raw material to achieve a specified weight percentage of each oxide by developing a system of linear equations. In a follow up paper, Khaimovich (2005) improved on the program to account for the cullet composition.

Changchit and Terrell (1990) developed a linear model to decide upon the amount of each raw material in ceramic batch calculation. The model objective function minimizes the batch cost. Linear constraints were included to ensure satisfying the desired ceramic properties.

Another two models were formulated to model the mixing problem in two different industries. The first is developed by Hayta, Mehmet, and Ünsal Çakmakli (2001) to find the optimum mix of wheat to produce break making flour. The other model, which was developed by Steuer, Ralph E. (1984), modeled the mixing process to form sausage.

In addition to raw material mixing contributions, several articles discussed the production planning of discrete processes. Díaz-Madroñero, Peidro, and Mula (2015) presented a review of mathematical models developed to tackle both production and transportation routing problem. The paper have presented how different models tackled various aspects including production, inventory, and routing. Although many papers tackled the production planning problem in discrete production, small attention is given to the production planning of continuous processes.

Fabian, Tibor (1958) developed an integrated production planning model for the continuous process of iron and steel production. The model was divided into three sections that were integrated at the end of the paper. The first part dealt with the production of iron. The second part of the model was formulated to represent the steel production operation. The final part dealt with the rolling operations. Assumptions were made to facilitate the solution and to guarantee linearity, such as constant batch size and constant size of the output.

In another two scholars, Dutta, Sinha, and Roy developed integrated production steel plant model. In the first (1990), the aim was to optimize the product mix taken into consideration allocation of plant capacities to different products, capacity expansion decisions, and the optimum route of a product across available machines. The second paper (1994) dealt with the allocation of energy in case of shortage. The model developed with the objective of maximizing profit, while considering energy as a limiting constraint.

Almada-Lobo, Oliveira, and Carravilla (2008) also tackled the production planning and scheduling of continuous process problem in coloured glass containers manufacturing. As a result of changing the product colour, setup time is required to change between colour and it's a sequence dependent process based on the two colours. A multi objective function was formulated to minimize the weighted sum of sequence dependent setup times, average inventory levels, and number of stock-outs.

In addition, Taşkın, and Ünal (2009) developed a MIP model for the production and transportation planning of a float glass manufacturing company called Trakya Cam. The company produces various product sizes in multi facilities. A model was built with the objective of minimizing the total cost including production, inventory, backorder, and transportation cost.

In this paper, a mathematical model is developed to integrate the production processes of fluorescent lamp starting from mixing of raw material till the storing of finished product. The model aimed at minimizing the total operating cost including, raw material, scheduled crushing, inventory at all levels, and energy cost, while. In the developed model, the optimum mix of raw materials is determined not only based on input variation as developed by Changchit and Terrell (1990), but also based on the optimum cullet ratio. Also, the energy cost is considered in the model to take into account the relationship between using glass cullet and energy saving as explained by Vishal, et. Al (2007) as well as Štefanić and Pilipović (2011). In addition to the mixing operation, the model takes into consideration the balance between an in-series continuous-process plant producing glass tubes followed by a discrete plant assembling fluorescent lamps. Integration between in sequence production stages is achieved, so that the demand of the following stage is a requirement from the previous stage. A major distinction between the developed model and the continuous models cited before is that the speed of the continuous process is not constant and it changes from one planning horizon to another depending on demand. Therefore, the amount of raw materials consumed and the output produced is dependent upon that variable.

4 MATHEMATICAL MODELING

4.1 Symbol Definitions

In the following three sections, the model constant parameter, sets, and decision variables are defined.

4.1.1 Constant Parameters

Symbol	Definition
$\%E_m$	Percentage of end-forming waste from the weight of straight tube size m
$\%G_m$	Percentage of cutting waste from the weight of glass tube size m
A_t	Available hours per period t
CB_t	Raw material batch Cost at period t
CC_m	Cost of crushing one glass tube of size m
CI^E_m	Monthly cost to keep one unit of end-formed tube of size m in inventory
CI^G_m	Cost of one glass tube in inventory of size m
CI^L_m	Cost to keep one lamp in inventory of size m
CN	Cost per m^3 of natural gas used in furnace
CP^E_m:	Cost to produce one unit of end-formed tube of size m
CP^L_m	Cost to produce one unit of lamp of size m
CR_i	Cost per Kg of raw material i
D	Outer diameter of glass tube
D_{mt}	Demand of fluorescent lamp of size m in period t
$F(MG\%)$	Relation between cullet ratio percentage, and natural gas consumption
F_{jk}	Chemical influence factor of oxide j on property k
H	Thickness of glass tubes
O_{ij}	Weight percentage of oxide j inside raw material i
P_{ij}	Weight percentage of oxide j inside raw material i
SI^B	Storage capacity of glass cullet
SI^E	Storage capacity of end-formed tubes
SI^G	Storage capacity of glass tubes
SI^L	Storage capacity of fluorescent lamps
SP^E_{mt}	Production capacity of end-formed tube of size m in period t
SP^L_{mt}	Production capacity of fluorescent lamps of size m in period t
SS^E_m	Safety stock of end-formed tubes of size m
SS^G_m	Safety stock of glass tubes of size m
SS^L_m	Safety stock of fluorescent lamps of size m
U^B	Lower limit for percentage of broken glass
U_j	Lower limit for percentage of oxide j
U_k	Lower limit of property k
U^P	Lower Limit of glass pull rate
V^B	Upper limit for percentage of broken glass (glass cullet)
V_j	Upper limit for the percentage of oxide j
V_k	Upper limit of property k
V^P	Upper limit of glass pull rate
W	Raw material batch Weight
X	Standard aggregate tube length
X_m	Standard length of glass tube m
Y_m	Size factor of tube size m
ρ	Density of glass

4.1.2 Sets

Symbol	Definition
I	Set of raw materials used to form the glass batch
J	Set of oxides forming the composition of the output glass
K	Set of required properties of the output glass, such as density and thermal expansion
M	Set of glass tubes sizes produced
T	Set of planning periods

4.1.3 Decision Variables

Symbol	Definition
B_t	Amount of broken glass (cullet) produced in period *t*
C_{mt}	Amount crushed of glass tubes of size *m* during period *t*
E_{mt}	Amount of end formed tubes *m* produced in period *t*
G_{mt}	Number of glass tubes of size *m* produced in period *t*
$I^B{}_t$	Inventory of broken glass at the end of period *t*
$I^E{}_{mt}$	Inventory of end formed tubes of size *m* at the end of period *t*
$I^G{}_{mt}$	Inventory of glass tubes of size *m* at the end of period *t*
$I^L{}_{mt}$	Inventory of fluorescent lamp *m* at the end of period *t*
L_{mt}	Amount of fluorescent lamps of size *m* produced in period *t*
P	Glass pull rate of glass from the furnace
$Q^E{}_{mt}$	Gross Requirements of end-formed tubes of size *m* during period *t*
$Q^G{}_{mt}$	Gross Requirements of glass tubes of size *m* during period *t*
R_{it}	Amount raw material *i* used in the glass batch in period *t*
$R^B{}_t$	Amount broken glass used in the glass batch in period *t*

4.2 Integrated Mathematical Model

4.2.1 Objective Function

The objective function is aimed at minimizing the total cost which includes the cost of production, inventory, scheduled crushed glass, raw material, and natural gas.

Min.

$$\sum_{m\in M}\sum_{t\in T}[CP^L.L_{mt}+CP^E.E_{mt}] + \sum_{m\in M}\sum_{t\in T}[CI^L.I^L_{mt}+CI^E.I^E_{mt}+CI^G.I^G_{mt}] + \sum_{m\in M}\sum_{t\in T}CC.C_{mt} + (A_t/W) * \sum_{i\in I}\sum_{t\in T}CR_i.R_{it} * P + CN * f(MG\%) * A_t \quad (1)$$

4.2.2 Constraints

1. Production Capacity Constraints

A. Mass production processes (fluorescent lamp assembly and end-formed tube production)

$$L_{mt} \leq SP^L_{mt}, \forall\, t \in T \,\&\, m \in M \quad (2)$$

$$E_{mt} \leq SP^{EF}_{mt}, \forall\, t \in T \,\&\, m \in M \quad (3)$$

B. Continuous flow processes (glass tube production)

$$\sum_{m\in M}(X_m/X) * G_{mt} - (A_t.P)/(\pi.\rho * X * h * (d-h)) = 0, \forall t \in T \quad (4)$$

Where the amount of glass tube produced in period *t* is equal to amount of molten glass produced in *t* (A_t*P) over the mass of one lamp.

The glass pull rate has an operating range as follows

$$U^P \leq P \leq V^P \quad (5)$$

C. Glass Cullet Production

$$B_t - (\pi.\rho.X_m * h * (d-h)).\sum_{m\in M}[(1-\%G_m).C_{mt} + \%G_m.G_{mt} + \%E_m.E_{mt}] = 0, \forall\, t \in T \quad (6)$$

The amount of cullet produced in *t* is equal to the mass of one lamp multiplied by the cut loss amount

2. Inventory Safety Stock

$$I^L_{mt} \geq SS^L_m, \forall\, t \in T \,\&\, m \in M \quad (7)$$

$$I^E_{mt} \geq SS^E_m, \forall\, t \in T \,\&\, m \in M \quad (8)$$

$$I^G_{mt} \geq SS^G_m, \forall\, t \in T \,\&\, m \in M \quad (9)$$

3. Storage Capacity

$$\sum_{m\in M} Y_m.I^L_{mt} \leq SI^L, \forall\, t \in T \quad (10)$$

$$\sum_{m\in M} Y_m.I^E_{mt} \leq SI^E, \forall\, t \in T \quad (11)$$

$$\sum_{m\in M} Y_m.I^G_{mt} \leq SI^G, \forall\, t \in T \quad (12)$$

$$I^B_t \leq SI^B, \forall\, t \in T \quad (13)$$

4. Linkage of In-Sequence Processes

$$Q^E_{mt} - L_{mt} = 0, \forall\, t \in T \,\&\, m \in M \quad (14)$$

$$Q^G_{mt} - E_{mt} = 0, \forall\, t \in T \,\&\, m \in M \quad (15)$$

5. Production & Demand Balance

$$I^{L}_{mt} - I^{L}_{m.(t-1)} + D_{mt} - L_{mt} = 0, \quad \forall\, t \in T \,\&\, m \in M \tag{16}$$

$$I^{E}_{mt} - I^{E}_{m.(t-1)} + Q^{E}_{mt} - E_{mt} = 0, \quad \forall\, t \in T \,\&\, m \in M \tag{17}$$

$$I^{G}_{mt} - I^{G}_{m.t-1} + Q^{G}_{mt} + C_{mt} - G_{mt} = 0, \quad \forall\, t \in T \,\&\, m \in M \tag{18}$$

$$I^{B}_{t} - I^{B}_{t-1} - B_t + A/W.P.R^{B}_{t} = 0\,, \forall\, t \in T \tag{19}$$

6. Oxide percentages upper limit & Lower Limits

$$U_j \le \frac{\left(\sum_{i\,\epsilon\, I} O_{ij}.\ R_{it}\right)}{\left(\sum_{j\,\epsilon\, J}\sum_{i\,\epsilon\, I} O_{ij}.\ R_{it}\right)} \le V_j, \forall\, t \in T \,\&\, j \in J \tag{20}$$

The numerator is the amount in Kg of oxide j in all raw materials and the broken glass divided by the yielded glass batch weight.

The equations can be written in following linear forms:

$$\sum_{\mathrm{i}\,\epsilon\,\mathrm{I}} O_{ij}.\ R_{it} - V_j \,.\left[\sum_{\mathrm{j}\,\epsilon\,\mathrm{J}}\sum_{\mathrm{i}\,\epsilon\,\mathrm{I}} O_{ij}.\ R_{it}\right] \le 0\,, \forall\, t \in T \,\&\, j \in J \tag{21}$$

$$\sum_{\mathrm{i}\,\epsilon\,\mathrm{I}} O_{ij}.\ R_{it} - U_j \,.\left[\sum_{\mathrm{j}\,\epsilon\,\mathrm{J}}\sum_{\mathrm{i}\,\epsilon\,\mathrm{I}} (P_{ij}.\ R_{it})\right] \ge 0\,, \forall\, t \in T \,\&\, j \in J \tag{22}$$

7. Broken glass percentage upper & lower limits

$$R^{B}_{t} - V^{B}.\left[\sum_{\mathrm{j}\,\epsilon\,\mathrm{J}}\sum_{\mathrm{i}\,\epsilon\,\mathrm{I}} O_{ij}.\ R_{it}\right] \le 0, \forall\, t \in T \tag{23}$$

$$R^{B}_{t} - U^{B}.\left[\sum_{\mathrm{j}\,\epsilon\,\mathrm{J}}\sum_{\mathrm{i}\,\epsilon\,\mathrm{I}} O_{ij}.\ R_{it}\right] \ge 0\,, \forall\, t \in T \tag{24}$$

8. Properties upper & lower control limits

For each oxide, the weight percentage of that oxide from the yielded batch weight is multiplied by a chemical influence factor (F)

$$\sum_{j \in J}\sum_{\mathrm{i}\,\epsilon\,\mathrm{I}} (F_{jk}.O_{ij}.\ R_{it}) - V_k \,.\left[\sum_{\mathrm{j}\,\epsilon\,\mathrm{J}}\sum_{\mathrm{i}\,\epsilon\,\mathrm{I}} O_{ij}.\ R_{it}\right] \le 0\,, \forall\, k \in K \,\&\, t \in T \tag{25}$$

$$\sum_{j \in J}\sum_{\mathrm{i}\,\epsilon\,\mathrm{I}} (F_{jk}.O_{ij}.\ R_{it}) - U_k \,.\left[\sum_{\mathrm{j}\,\epsilon\,\mathrm{J}}\sum_{\mathrm{i}\,\epsilon\,\mathrm{I}} O_{ij}.\ R_{it}\right] \ge 0\,, \forall\, k \in K \,\&\, t \in T \tag{26}$$

9. Batch Weight

$$\sum_{i \in I} R_{it} \ge W, \forall\, t \in T \tag{27}$$

10. Non-negativity Constraint

All variables are higher than or equal to zero.

5 COMPUTATIONAL WORK

5.1 Computational Plan

In order to validate the model, it is tested against base case data given by Al-Arabi Lamp and Glass Factory. The model is used to generate the same output variables, such as production and inventory amounts. Input data includes actual demand forecast for six months, cost figures for production, inventory, and crushing, raw material chemical composition, etc. Therefore, the plan goes as below:

- Linear approximation techniques are used for the non-linear terms in the objective function and constraints to transform the integrated model into linear.
- The base case input parameters are fed to the model and the results are compared vs. the actual output variables to prove model validity.
- Then, the integrated model is solved and the optimum solution is compared with Al-Arabi actuals.
- The last step is to test the sensitivity of the integrated model to variability in the raw material, energy, and crushing cost values. Different scenarios are tested and the model response is observed and analyzed.

All computational runs are solved using IBM-ILOG CPLEX V.12.6.2 on an i7 HP ProBook4540s, and the following assumptions are made:

- Raw material chemical compositions are fixed over the planning horizon
- Glass pull rate are fixed over the planning horizon, so once decided by the model, the values are the same from one period to the other.

5.2 Linear Approximations

5.2.1 Separable Programming Techniques

In order to solve the model as linear, the batch cost term in the objective function (1), and the glass cullet inventory balance constraints (19) needs to be linearized. Moreover, a relationship between the glass cullet percentage, and energy cost should be figured out. First, the linearization of constraint (19) and the batch cost term are done using separable programming techniques, where the right hand side of the equation can be expressed as the sum squared of the two variables instead of multiplying both variables. Faragallah (2016)

$$Z_{1.t} = (P + R_t^B)/2 \ , Z_{2.t} = (P - R_t^B)/2 \quad (28)$$

$$Z_{1.t}^2 - Z_{2.t}^2 = P \, . R_t^B \quad (29)$$

It is shown that for the given operating range of glass pull rate (P) and the broken glass (R_t^B), Z_1^2& Z_2^2 can be expressed as linear functions as shown in figure 1.

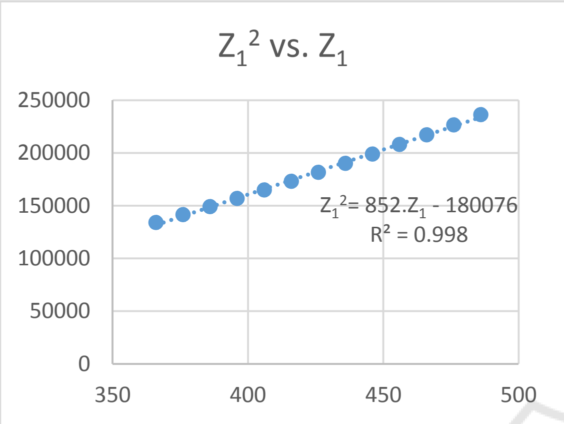

Figure 1: Linear Approximation for the Multiplication of P & R_t^B.

Therefore, (19) can be expressed as

$$B_t - I_t^{BG} + I_{t-1}^{BG} = A/W * (144.\text{P} + 708.R_t^B - 101952) \quad (30)$$

The same methodology is used for the batch cost term in the objective function, so the term can be transformed into:

$$1.44.\textstyle\sum_{t\epsilon T}(245.216.P - 508.698.R_t^B + 73252.5) \quad (31)$$

5.2.2 Natural Gas Cost Formulation

According to Vishal, et. Al (2007) as well as Štefanić and Pilipović (2011), the energy consumption of melting glass is reduced by 2.5 – 3% for every 10% of glass cullet addition to the batch. The average natural gas consumption at 30% glass cullet ratio is 742 m^3/hr. (Abdelrahman 2015) Therefore, a relationship can be derived between the natural gas consumption and the cullet percentage as shown below

$$F(MG\%) = -86*MG\% + 312.18 \quad (32)$$

Therefore, the last term representing the natural gas consumption cost in (Eq. 34) can be expressed as:

$$720.C_{NG}.(-86.(MG\%) + 312.18) \quad (33)$$

Where $(MG\%) = (R_t^B)/(\sum_{j\epsilon J}\sum_{I\epsilon I} PO_{ij}.\ RM_i) \quad (34)$

The term in (32) is a non-linear term, however, from 2015 batch data from Al-Arabi factory, the denominator for the operational range of cullet percentage has an average value of 442.49 and a standard deviation of 2.03. The model is tested with the average value, and plus and minus 3 standard deviations from the average, and the difference between the three cases was neglected, so the average value of 442.49 is used. Faragallah (2016)

5.3 Validation & Results

The developed model is used to generate the base case data provided by Al-Arabi. Table 1 and table 2 show the demand data for 2014 and cost figures used as an input. Table 3 shows the chemical composition and oxide percentages of raw materials used. All the input data was obtained from Al-Araby Glass Factory. (Abdelrahman 2015)

Besides these data, the glass factory actual plan was to set GPR at 750, cullet ratio of 30%, and to run production for 19 hours a day, and 5 hours per day of crushing. The plant total cost of production, inventory, crushing, raw material, and energy was LE **29,648,991**.

These are the operating parameters fed to the model and it proves efficiency by generate the same production and inventory amounts of glass, end-formed tubes, and lamps

Based on the input data, the number of decisions variables are 188 and the number of constraints are 404 with 96 equalities constraints. The model is solved in almost 240 seconds using CPLEX.

Then the model was solved to provide the optimum solution, which is to run the glass factory at 646 Kg/hr and a cullet ratio of 30%. Table 1, 2 & 3 provides the detailed optimum solution. The total cost of the whole planning horizon, including discrete process production cost, inventory cost, crushing, raw material, and energy cost is equal to

22,488,970 + 739,000 + 1,194,102 + 1,408,674 + 1,634,000 = LE **27,464,746**

With a total savings of LE **2,184,245** over that of Al-Arabi lamp and glass factories actuals.

Table 1: Optimum Result of End-Formed Tubes (EF) & Lamps for 40 Watts.

Month	40 Watts lamp, 1000s units				
	Demand	Units Produced		Inventory Level	
		EF	Lamp	EF	Lamp
July	1,388.8	1,388.8	1,388.8	360	1,386
Aug	1,591.2	1,591.2	1,591.2	360	1,386
Sept	1,586	1,586	1,586	360	1,386
Oct	1,433.9	1,433.9	1,433.9	360	1,386
Nov	1,771.9	1,771.9	1,771.9	360	1,386
Dec	1,739.4	1,739.4	1,739.4	360	1,386

Table 2: Optimum Result of straight tubes for 40 Watts.

Month	40 Watts, 1000s units			
	Required	Produced	Inventory	Crushed
July	1,388.8	1,764.3	1,386	375.47
Aug	1,591.2	1,721.5	1,386	130.3
Sept	1,586	1,721.5	1,386	135.5
Oct	1,433.9	1,878.7	1,386	444.77
Nov	1,771.9	1,814.5	1,386	425.91
Dec	1,739.4	1,752.9	1,386	135.32

Table 3: Optimum Glass Batch Mix.

Parameter	Output
silica sand (Kg)	189.80
Soda Ash (Kg)	81.00
Dolomite (Kg)	45.20
Feldspar (Kg)	35.80
Borax (Kg)	4.90
Limestone (Kg)	7.82
Alumina (Kg)	0.00
Sulphate (Kg)	0.91
Carbon (Kg)	0.06
MG (Kg)	132.50
Density (gm/cm^3)	2.488
Thermal Expansion (10^{-7}*K^{-1})	100.60
Batch Cost, LE	271.61

5.4 Sensitivity Analysis

In this section, the impact of various cost figures on the optimum solution is observed and analyzed. The production cost is a major component of the total cost structure, however, the production cost is driven by the demand for lamps. Therefore, the focus is on the effect of crushing, raw material, and energy cost on the model results. A summary of the cost structure for the optimum solution of the integrated model is shown below:

Raw Material Cost = MLE 1.4086
Energy Cost = MLE 1.634
Crushing Cost = MLE 1.194
Inventory Cost = MLE 0.739
Production Cost = MLE 22.489
Total Cost = MLE 27.46

5.4.1 Impact of Raw Material & Natural Gas Cost

Changes in Soda Ash, Silica Sand, and Borax cost per ton are included in the sensitivity because they represent more than 80% of the raw material cost value. Based on historical data, changes in the cost per ton for these materials are forecasted based on the worst case scenario. Faragallah (2016) The same was done for natural gas cost. However, the raw material cost and the energy cost in the total cost function increased without affecting the optimum solution. Therefore, the model is insensitive to changes in Silica Sand, Soda Ash, Borax, and natural gas cost figures given that the remaining cost figures of the objective function do not change.

5.4.2 Impact of Crushing Cost

The crushing cost at Al-Arabi factory is the conversion cost to melt 1 Kg of glass cullet and transform it to glass tubes again. (Elbendary 2015) In order to reduce the crushing cost, the factory can outsource percentage of the glass cullet. With close chemical composition to that of the factory, the outsourced cullet cost is 500 LE/ton. (Abdelrahman 2015)

Therefore, the effect of mixing the outsourced cullet with the current batch mix is tested for different percentages of outsourced cullet (5% - 20%).

Increasing the outsourced cullet percentage up to 5% causes the crushing cost and the glass pull rate to decrease. Figure 2 summarizes the effect of outsourced cullet over the crushing cost.

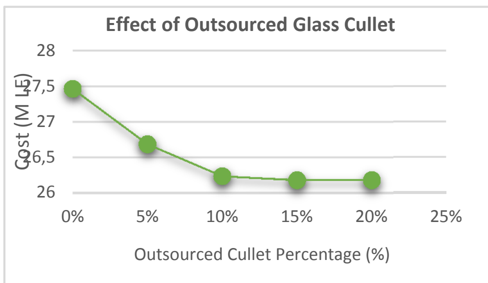

Figure 2: Total cost versus outsourced Cullet Percentage.

From the above figures, increasing the outsourced cullet percentage more than 15% doesn't have an impact on the optimum solution. Therefore, the optimum solution of the integrated model is achieved with 15% outsourced cullet ratio.

At this ratio, no crushing of straight tube is needed. Therefore, the required cullet ratio in the batch mix is achieved through the outsourced cullet and the cut loss from operation. Accordingly, the crushing cost is eliminated, the raw material and energy cost is reduced because the optimum cullet ratio in the batch mix changed from 30% to 35% due to the introduction of outsourced cullet.

6 CONCLUDING REMARKS

Integration of batch, continuous, and discrete manufacturing processes in florescent lamp manufacturing was researched. In literature, glass batch mixing, and continuous production planning for glass furnaces were treated separately in the literature found each by its own. Therefore, a mathematical model was formulated to integrate the optimum mixing of glass batch along with the production planning of discrete glass tubes and florescent lamps. The main factors affecting the manufacturing process were considered. These factors are the glass pull rate of molten glass from the furnace which control the amount of glass tubes produced, the percentage of glass cullet used in the batch which affects the amount of crushed tubes to meet the required cullet ratio, the optimum mix of raw materials, and inventory levels of glass tubes and lamps. The objective function was to reduce the total manufacturing costs including crushing, raw material, inventory, production cost, and energy cost as a function in glass cullet percentage. The objective function and some of the constraints contained non-linear terms. Separable programming methods were used to linearize the model. Then, different Scenarios were tried to test the effect of various parameters on the optimum solution. It was found that changing in raw materials and energy cost values changes the objective function value without affecting the optimum solution. Moreover, trials were made to reduce the crushing cost through using glass cullet from outside sources. It was found that with increasing the amount of outsourced cullet, the glass pull rate along with the crushing cost decreased dramatically till reaching zero. Also, the glass cullet percentage increased causing the raw material and energy costs to decrease. As a result, the total cost decreases with the increase of outsourced cullet ratio till reaching a constant value. Therefore, using outsourced cullet ratio will help reducing the amount of glass crushing, raw material cost, and energy consumption.

The model proved to be a very helpful tool for designing the optimum batch mix based on the raw material chemical composition. In addition, the model will facilitate the planning process of the two factory as an integrated entity and will help improving the total cost.

For future works, the model can be extended to include diversification of customers of the glass factory, which will reduce the unit cost. Deals from other customers, such as other lamp producers, laboratory glass ware companies, etc., should be considered to increase the amount produced of glass tubes. The following issues need to be taken into account in selecting future customers:

- Quantities requested by the customer while staying within the capacity of the glass factory.
- Customization of each order, such as different diameters and lengths which will introduce set-up time to change from one product to another. For example, changing tube diameter may require to change the GPR. This will cause production to stop for some days based on the amount of change and this may delay production to the main customer which is the lamp factory, or to other customers the factory decides to deal with.
- Price discounts given to each customer based on the quantity ordered and the level of customization from the current situation.

REFERENCES

Abdelrahman, Khaed. Personal interview. 27 Sept. 2015

Almada-Lobo, Bernardo, José F. Oliveira, and Maria Antónia Carravilla. "Production planning and scheduling in the glass container industry: A VNS approach." *International Journal of Production Economics* 114.1 (2008): 363-375.

Changchit, Chaweng, and M. Palmer Terrell. "A mathematical model for the calculation of ceramic batch formulas." *Applied Mathematical Modelling* 14.12 (1990): 641-648.

Díaz-Madroñero, Manuel, David Peidro, and Josefa Mula. "A review of tactical optimization models for integrated production and transport routing planning decisions." *Computers & Industrial Engineering* 88 (2015): 518-535.

Dutta, G., G. P. Sinha, and P. N. Roy. "Product-Mix Optimizer for an Integrated Steel Plant." (2000).

Dutta, Goutam, et al. "A linear programming model for distribution of electrical energy in a steel plant." *International Transactions in Operational Research* 1.1 (1994): 17-29.

Elbendary, Farid. Personal interview. 27 Sept. 2015

Fabian, Tibor. "A linear programming model of integrated iron and steel production." *Management Science* 4.4 (1958): 415-449.

Faragallah, Mina W. "Optimization of Integrated Batch Mixing & Continuous Flow in Glass Tube & Fluorescent Lamp." *MS Thesis. The American University in Cairo* (2016).

Hayta, Mehmet, and Ünsal Çakmakli. "Optimization of wheat blending to produce bread making flour." *Journal of food process engineering* 24.3 (2001): 179-192.

Khaimovich, M. M., and K. Yu Subbotin. "Automation of batch formula calculation." *Glass and Ceramics* 62.3-4 (2005): 109-112.

Khaimovich, M. M. "Account of cullet composition in calculation of batch formulas." *Glass and Ceramics* 62.11-12 (2005): 381-382.

Sardeshpande, Vishal, U. N. Gaitonde, and Rangan Banerjee. "Model based energy benchmarking for glass furnace." *Energy Conversion and Management*48.10 (2007): 2718-2738.

Štefanić, Nedeljko, and Ana Pilipović. "Impact of glass cullet on the consumption of energy and environment in the production of glass packaging material." *Proceedings of the 9th WSEAS International Conference on Environment, Ecosystems and Development-EED'11*.

Steuer, Ralph E. "Sausage blending using multiple objective linear programming." *Management Science* 30.11 (1984): 1376-1384.

Taşkın, Z. Caner, and A. Tamer Ünal. "Tactical level planning in float glass manufacturing with co-production, random yields and substitutable products. "*European Journal of Operational Research* 199.1 (2009): 252-26.