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A Neuro-Fuzzy Linguistic Approach in Optimizing the Flow Rate of a Plastic Extruder Process

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Abstract: The plastic extruder system is an important process in the solid waste recycling system. This paper optimizes the flow rate of this process with the application of a neuro-fuzzy model. The model identifies a specified desired output from a large number of input parameters. The methodology adopted is neuro-fuzzy. The concept of neuro-fuzzy is not new as a research methodology but new in its applied form to plastic recycling extruder process. The result obtained indicates the feasibility of applying the methodology in this instance. Thus, the study may be extended to other recycling processes apart from plastic base. The study is predicated on the need to attain more precision in the derivation of optimal values for the plastic extruder system in recycling plant. The research has strong economic implications since it has theory with an applied bias on a problem experienced by the industry. It can be used by managers in the plastic industry, or practitioners i.e those supporting practice such as consultants or software developers, to mention a few. The work particularly has an economic justification. Intrinsically, the result obtained being an improvement over what was reported by earlier researchers is noteworthy. The paper is new in that it appears to be the first application of neuro-fuzzy in the system being researched.

Keywords: Plastic extruder, Neuro-Fuzzy

Plastik Püskürtme Yönteminde Akış Oranı Optimizasyonu için Bulanık Mantık Yaklaşımı

Özet: Plastik püskürtme sistemi katı atık geri dönüşüm sistemi içinde önemli bir yöntemdir. Bu çalışma bulanık mantık kullanılarak yönetmin akış oranını optimize eder. Model giriş parametrelerinin büyük değerlerinden istenilen spesifik çıkış değerlerinin tanımlanmasını sağlar. Uygulanan metod bulanık mantık yöntemidir. Bulanık mantık yöntemi yeni bir araştırma metodu olmamakla birlikte plastik püskürtme yöntemine uygulanması bakımından yeni bir metodtur. Elde edilen sonuç verilen bu örnek için metodun uygulanabilirliğini gösterir. Böylece, çalışma plastik dışında diğer geri dönüşüm yöntemleri için geliştirilebilir. Çalışma geri dönüşüm fabrikalarındaki plastik püskürtme sistemi için optimal değerleri türetmede daha gerçekçi değerler elde etme gereksimine dayanır. Teori endüstriyel deneyimler sonucu oluşan bir probleme dayanan uygulama olduğu için araştırmanın ekonomik zorlukları vardır. Çalışma plastik sanayindeki yöneticilere, yazılımcılara, danışmanlara uygulama desteği sağlama açısından kullanılabilir. Çalışma özellikle ekonomik açıdan bir haklılığa sahiptir. Aslında, elde edilen sonuç daha önceki araştırmacılar tarafından söylenen şeylerin üzerine bir ilerleme olarak elde edilir. Makale araştırılan sistemde bulanık mantık yönteminin ilk uygulaması olarak görünmesi açısından yenidir.

Anahtar Kelimeler: Plastik Püskürtme, Neuro-Fuzzy

1. Introduction

The purpose of the paper is to develop a neuro-fuzzy approach in the quantification of the flow parameters for an extruder process in a plastic recycling plant [1-4]. The study is motivated by the growing concern among the various stakeholders world over. Governments, consumers and the various stakeholders in environment increasingly pursue the drive to a zero-level pollution. Thus, there is a focus on controlling the enormous amount of wastes generated from materials either during the manufacturing process or at the disposal stage of finished goods. In manufacturing, this effort has yielded results with carefully laid-out programmes to promote "environmentally conscious manufacturing".

The various governments (state and central) in many parts of the world have adopted measures aimed at controlling the compliance of manufacturing organizations to "environmentally conscious manufacturing" by compelling organizations to submit statutory reports on environmental conscious manufacturing. This requirement has improved environmental friendliness a great deal. Thus, the negative impacts of environmental unfriendliness are greatly reduced if not eliminated in many instances.

Consequently, the government is encouraging recycling and recycling practices [5, 6]. For example, a strong indication of the "end-of-life directive" endorsed by the European Union States that if resources are not recycled, a period may come that very limited resources would be available for mankind [7]. Consequently, we may need to suffer for the shortages of these important resources.

Recycling industries face serious economic problems that increase the cost of recycling [8-11]. By way of proffering solution, a number of management strategies are adopted over time. Such strategies may include business process re-engineering, downsizing, system restructuring, lean manufacturing, etc. All these strategies are aimed towards optimizing the system variables through minimization of costs and maximization of profits. The extruder in a recycling plant is one of the most important components of the system that dictate the unit cost of production, and consequently, the profit made by the system [12]. Adequate design and control of flow rates is obviously necessary towards optimization of the recycled product [13-16]. To the authors' knowledge, no documentation seems to have been made on this respect. This paper is therefore an effort to model the flow rates of an extrusion with particular reference to the plastic recycling industry.

2. Methodology

The approach to this paper is the use of neuro-fuzzy model to arrive at a specified desired output in the optimization approach for solid waste recycling. The neuro-fuzzy model combines the fuzzy logic and neural network principles to generate a model that will result in the evolution of a specified desired output. The process followed here is that of comparing the output parameters of the optimized flow rate of an extruder to input parameters for subsequent processing by the use of neuro-fuzzy model. Thus, we arrive at the specified desired output. Considering the output parameters from the model we have the following:

(i) $(\dot{Q} - h)$ = Positive (P) = Optimistic (O_p)

(ii) $(\dot{Q} - h)$ = Negative (N) = Pessimistic (P_e)

(iii) $(\dot{Q} - h)$ = Zero (Z) = Normal (N)

where. $\dot{Q}$ = Rate of flow of the molten solid waste recycled

h = parameter(s)/factor(s) responsible for the rate of flow of the solid waste

O_p = Optimistic (where solid waste flow is maximum)

P_e = Pessimistic (solid waste flow is minimum)

N = Normal (solid waste flow is just normal)

The neuro-fuzzy model recognizes the above output parameter as input parameters and then processed to arrive at the specified desired output. Considering the neuro-fuzzy model structure given in the figure below (Fig. 1), we have:

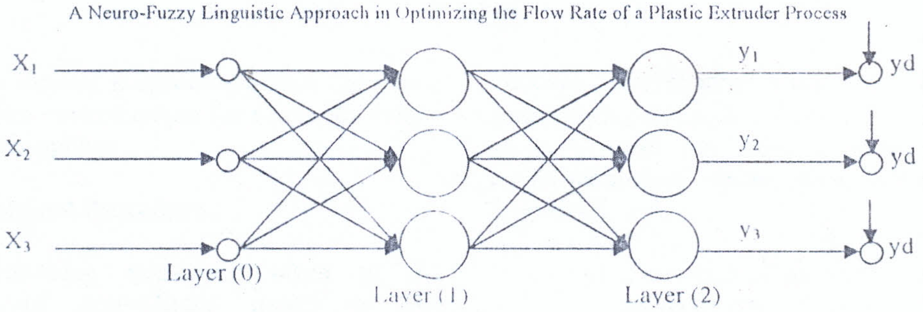

Fig. 1 showing the structure of neuro-fuzzy model

For simplicity, the neuro-fuzzy model is represented with the following schematic diagram of the model layout (Fig. 2):

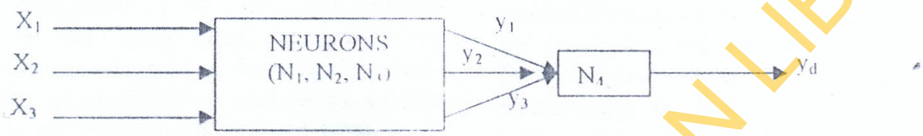

Fig. 2: A layout of neuro-fuzzy model

Note:

X_1, X_2, X_3 represent input parameters
Layers 0, 1, 2 and N_1, N_2, N_3 and N_4 represent connections between the input and output parameters.
y_1, y_2, y_3 represent the output parameters
y_d represents the desired output

For the processing of the parameters to arrive at the specified desired output, the following base-rules are employed:

(i) IF ($\dot{Q}$ - h) = P, AND ($\dot{Q}$ – h) = P continues, THEN output = O_p
(ii) IF ($\dot{Q}$ - h) = P_e, AND ($\dot{Q}$ – h) = P_e continues, THEN output = Nil
(iii) IF ($\dot{Q}$ - h) = N, AND ($\dot{Q}$ – h) = N, THEN output = Nil

The desired output aimed at is Op, a condition of optimistic where the flow rate of the extruder is maximized. With the factor responsible for flow rate (extrusion chamber) contained in design such that maximum molten solid waste flow through, the desired output will be attained, and this is the objective of the neuro-fuzzy model. For the sake of computation, the following system operating rules are formulated:

System Operating Rules

INPUT # 1: ("Input," Positive (P), Negative (P_e), Zero (N))
INPUT # 2: (GP – Getting Positive (P), Getting Negative (Pc), Getting Normal (GN))
CONCLUSION: ("Output", Optimistic (O_p), Pessimistic (P_e), Normal (N))
INPUT #1: System Status
Input: ($\dot{Q}$ - h)
P = Optimistic, P_e = Pessimistic, N = Normal
GP = Getting Optimistic, GP_g = Getting Pessimistic, GN = Getting Normal
OUTPUT Conclusion & System Response
OUTPUT O_p = Optimistic, P_e = Nil, N = Nil

The point of interest is attaining output O_p, which is the specified desired output for which the neuro-fuzzy model is applied.

3. Computational Procedure

The following steps are taken in the application of neuro-fuzzy model to the optimization of flow rates of an extruder. The conventional model framework of the optimization of flow rates of an extruder is compared with the model framework of the neuro-fuzzy model. In the comparison, it is discovered that the model framework of the neuro-fuzzy model is more favourable compared with the conventional framework in the sense that the parameters considered for optimization of flow in the neuro-fuzzy model is relatively fewer than the parameters considered in the conventional model framework. The edge the fewer parameters in neuro-fuzzy model have over the numerous ones in the convectional model framework is that the cost of achieving an optimized flow rate is greatly reduced with fewer parameters compared with many parameters.

Looking at the comparison between the conventional model framework and that of the neuro-fuzzy model we have the following:

Conventional Modelling Framework

The parameters considered for the optimal functioning of the extruding machine are as follows:

- Flow rate of the extruder (Q)
- Channel Width (W)
- Screw diameter (D)
- Helix Angle (θ)
- Screw Speed (N)
- Metering Zone Length (L)
- Apparent Viscosity (μa)
- Pressure (P)

For cost effectiveness the optimized model was developed to become a function of a seven (7) parameters instead of eight (8) i.e. (i) screw diameter (d), (ii) screw speed (N), (iii) apparent viscosity, (iv) channel width (W), (v) metering zone length (L), (vi) helix angle (θ), (vii) flow rate of the extruder (Q). Looking at the neuro-fuzzy model parameters on the other hand we have the following:

- Flow rate of the recycled solid waste material (Q)
- Frictional effect between the surfaces of the solid material and the walls of the extruder (internal walls) (Fe)
- Diameter of the extruder (D)

The cost of optimizing the flow rate is concentrated at reducing the frictional effect (Fe) and increasing the diameter of the extruder (D). This simplicity makes cost effectiveness more encouraging in applying neuro-fuzzy model to optimization of flow rates, which gives the neuro-fuzzy model an edge over the conventional model.

The neuro-fuzzy model is applied to the optimization of flow rate of an extruder to simplify the rigours of and the less effective mathematical processes involved in generating the conventional model.

4. Case Study

This section reports a case example of a study carried out in the process of optimising the flow rate of substances from an extruder in a plastic recycling process. The hypothetical company's name is SOLITECH. In 2004, it was discovered that the quantity of solid plastic recycled was dependent on the diameter of the extrusion chamber and the frictional effect between the plastic material and the walls of the chamber which accounts for the flow of the material to be recycled. SOLITECH SOLID WASTE RECYCLING (NIG) LTD adopted the use of neuro-fuzzy model in controlling the recycling process to ensure that the condition necessary for maximum flow of solid plastic material recycled was attained.

The attainment of maximum flow condition if termed "optimizing flow rate". It was discovered that drag in the flow of plastic material occurred whenever frictional effect between the surfaces of material and walls of chamber increased. This drag in flow led to low flow rate of the recycled material. This condition must be avoided to maximize plastic material flow rate. Although the parameters affecting the flow rate are frictional effect and the diameter of the extrusion chamber, the major determinant of variation in flow rate is the frictional effect since the diameter of the chamber is constant. The neuro-fuzzy model was thus applied to take care of these wide variations in flow rate due to the variations in the frictional effect.

Applying the neuro-fuzzy model to maximize flow rate of solid plastic material recycled, we have the following neuro-fuzzy model components:

Input Parameters: (i) Quantity of solid plastic waste materials to be recycled (Q)

(ii) Frictional effect between the surfaces of material and walls of extrusion chamber (Fe)

(iii) Diameter of the extrusion chamber (D)

Output Parameters: (i) High flow rate (HFR) (Optimistic, O_p)

(ii) Low flow rate (LFR) (Pessimistic, Pe)

(iii) Normal flow rate (NFR) (Most Likely, M_L)

Linguistic Variables: (i) $\{Q - \Sigma FeD\}$ = Positive (P) = HFR = Optimistic (O_p)

(ii) $\{Q - \Sigma FeD\}$ = Negative (N) = LFR = Pessimistic (O_e)

(iii) $\{Q - \Sigma FeD\}$ = Zero (Z) = NFR = Most Likely (M_L)

Representing the neuro-fuzzy model structure with a network we have (Fig. 3):

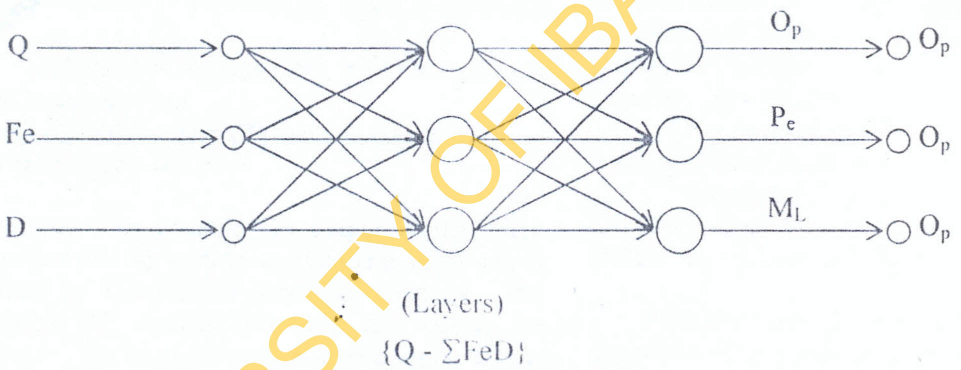

Fig. 3: Neuro-fuzzy Model Structure Networks

Where Q, Fe, D = input parameters, O_p, P_e, M_l = output parameters, O_p = desired output

For more simplicity the neuro-fuzzy model can be represented with the use of the following schematic diagram:

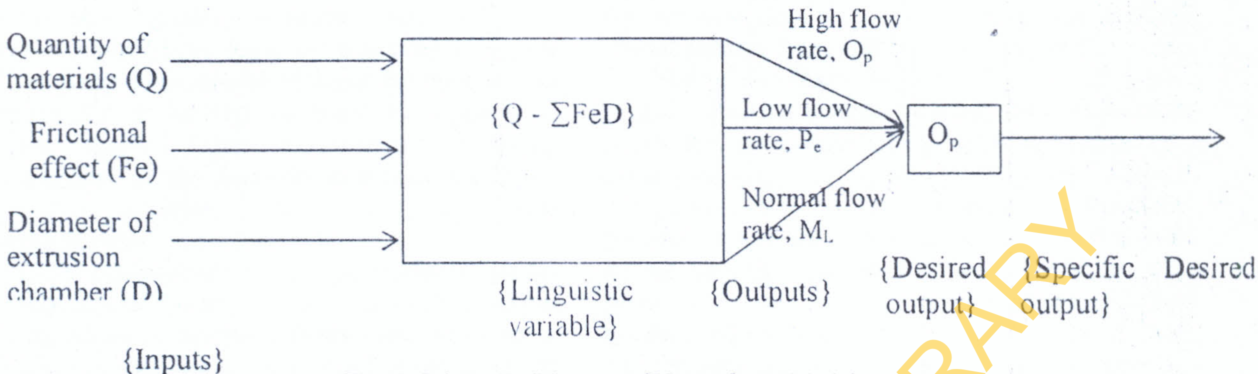

Fig. 4: Schematic Diagram of Neuro-fuzzy Model

These neuro-fuzzy components are combined with the use of neuro-fuzzy commands "IF", "AND" "Continues" and "THEN" to develop a rule-structure followed in the use of the model as follows (Fig. 4):

IF {Q - ΣFeD} = Positive (P), AND P continues
THEN output = O_p
IF {Q - ΣFeD} = Negative (N), AND N continues
THEN output = Nil
IF {Q - ΣFeD} = Zero (Z), AND Z continues
THEN output = Nil

Note: The positive (P) output implies high flow rate (HFR) leading to optimistic (Op) output desired by SOLITECH recycling company. The negative (N) implies low flow rate (LFR) not desired. The zero (Z) output implies normal flow rate (NFR) not desired. The concern of the neuro-fuzzy model is to help SOLITECH reach out for the specified desired output of optimistic (Op) where the flow rate of the recycled solid plastic material is maximum.

For computational purpose, a system operating rule for the neuro-fuzzy model is given as follows:

System Operating Rules

INPUT #1: {"Input", (Q - ΣFeD) = P, (Q - ΣFeD) = N, (Q - ΣFeD) = Z}
INPUT #2: {"Input", Pcontinues, Ncontinues, Zcontinues}
CONCLUSION: {"Output", Optimistic (O_p), Pessimistic (P_e), Most Likely (M_L)}
INPUT #1: System Status
Input #1: {Q - ΣFeD}
P = Positive, N = Negative, Z = Zero
Input #2: {Q - ΣFeD} continues
Pcontinues, Ncontinues, Zcontinues
OUTPUT: Conclusion & System Response
Output: O_p = Optimistic, P_e = Nil, M_L = Nil

Note: the neuro-fuzzy model only recognizes the optimistic (O_p) condition representing the specified desired output where the flow rate of the recycled solid plastic material is maximum.

5. Discussion of Results

The neuro-fuzzy model is designed to control a functioning system to attain to a specified desired output. In this case study of recycled solid plastic material by SOLITECH SOLID WASTE RECYCLING (NIG.) LTD, the specified desired output attained with the aid of neuro-fuzzy model is the condition of maximum flow rate of recycled plastic material (High flow rate – HFR) referred to by the model as optimistic (Op) output. The neuro-fuzzy model converts one of the fundamentals (fuzzy-logic control model output) of the fuzzy-logic model to input parameters and process the parameters to attain to a specified desired output. Other fundamentals or basic components of the fuzzy-logic model are input, linguistic variables, rule matrix and system operating rules.

The components of the neuro-fuzzy model namely inputs, layers, outputs and desired output are connected in the neuro-fuzzy structure network (Fig. 1a) in such a way as to arrive at the specified desired output aimed at by SOLITECH. The input parameters are linked to the output parameters by means of the layers – which are made up of linguistic command or interrelationship between the parameters. These layers perform the similar function as the neurons in the human neural system where the neurons form a network of links connecting vital information leading to the desired destination. The destination in the case of the neuro-fuzzy model is the specified desired output. The name neuro-fuzzy got its derivative from the word neurons in the neural system in human while fuzzy is coined from the fuzziness with which the model accommodates wide variations in input parameters for processing to arrive at the specified desired parameter (output).

Other vital components of the neuro-fuzzy model are rule-structure and system operating rules. The rule structure is made up of neuro-fuzzy commands of "IF", "AND", "Continues" and "THEN" carefully connected together to arrive at the specified desired output. The system operating rules contain programmable rule statements for the sake of computerization. The system operating rules encompass virtually all the components of the neuro-fuzzy model in such a way that a computer program can be written on them for computerization. The neuro-fuzzy commands of "IF", "AND", "Continues" and "THEN" have significant meanings that account for the effectiveness of the model. The command "IF" means if the outcome of the relationship between input and output parameters is this, the command "AND" means "and this outcome", the command "continues" means "the outcome continues over time, finally the command "THEN" means if all the previous commands hold "then the system should prompt the specified desired output".

The neuro-fuzzy model schematic diagram (Fig. 2) shows a simplified form, the connections within the neuro-fuzzy components right from the input parameters to the specified desired output. The major link is the connection between the input parameters and the output parameters represented by the linguistic variable. In this case study, the linguistic variable is the relationship between the quantity (Q) of the solid waste material recycled and the parameters determining the rate of flow of the material. These are namely effective frictions between the surfaces of the material and the walls of the extruding chamber (Fe) and the diameter of the chamber (D). The linguistic variable connecting these parameters is given by $\{Q - \sum Fe.D\}$. This serves as the major connection between the input parameters and the output parameters. The connections lead to the final destination of specified desired output of High Flow Rate (HFR) of the solid waste material that is termed optimistic (Op) output. The essence of the neuro-fuzzy model schematic diagram is the simplicity with which the neuro-fuzzy model components are interrelated to arrive at the final destination desired. Hence, the process undertaken by the neuro-fuzzy model in arriving at the specified desired output can be viewed at a glance in the neuro-fuzzy model schematic diagram.

The model is designed such that the most favourable condition where maximum quantity of solid waste material is recycled is attained. The linguistic variable serves as the engine of the model in bringing about relationship between the input and the output parameters to evaluate the outcome of such relationship. In this case study the linguistic variable is $\{Q - \sum Fe.D\}$= Positive (P) or Negative (N) or Zero (Z), where Q = quantity of solid waste material recycled, Fe = effective frictional force between the surfaces of the material and the walls of the extrusion chamber and D = diameter of the extrusion chamber. The designation Σ denotes summation. The input parameters Fe and D determine the rate of flow of the solid waste material to be recycled through the extrusion chamber. The higher the value of this parameter the lower the flow of solid material and the lesser the quantity of the solid waste material (Q) recycled. The major parameter that determines the flow rate is the Fe effective friction since the diameter (D) of the extrusion chamber is fixed. The neuro-fuzzy model is thus designed to focus on the condition where the value of the parameters {ΣFe.D} is at the barest minimum. At this condition, maximum flow of the solid waste material is attained, hence, maximum quantity (Q) of the material is recycled. This condition is defined by the linguistic variable {Q - ΣFe.D} = POSITIVE (P), which ultimately leads to the specified desired output of optimistic (Op) where the flow rate of meter is maximum (HFR). Other outputs of the model which show deviation from this specified desired output are designated Nil – meaning, not recognized by the neuro-fuzzy model.

With the help of the neuro-fuzzy model, the SOLITECH Solid Waste Recycling (SSWR) Ltd. can design its solid waste recycling facilities in such a manner that will enable it maintain the condition of lowest frictional effects. These effects are between the surfaces of the recycled solid waste material and the walls of the extrusion chamber to allow for recycling of the maximum quantity of solid waste materials.

6. Conclusions

The expectations of investors and practitioners are changing about the solutions that researchers proffer to problems that exist practice. There is particular interest of investors and practitioners in the plastic recycling industry of the need to utilize improved solution techniques that would generate better result than before. This mandates greater capacity for self analysis and improvements of models presented by researchers in this sector of the economy. The central aim of this research is to familiarize practitioners and investors in the plastic recycling industry with an analytical approach that could be used to optimize the flow rate of an extruder in the system. The task has been demonstrated in the earlier part of this paper. Particularly, the paper presents an optimization process for the flow rate of a plastic recycling system with the application of neuro-fuzzy model.

Four interesting questions relating to the problem solved here, which the current and potential users of the article may ask are (i) what are we going to learn from the article that we do not know now? (ii) Why is it worth knowing? (iii) How do we know that all conclusions are valid? (iv) What does the future hold in reformulating and developing the model?

Prior to the emergence of this paper, it seems that no documentation has addressed the problem of extruder flow process optimization in a plastic recycling system. This is new knowledge that the article is proposing but not yet documented until now. The article is worth knowing in view of the economic implication that it has in the industry. With the application of the model, it may be feasible to find an optimal value of the flow rate of an extruder in a plastic recycling system. In view of the uncertainties that may exist in the measurement of the flowrate and its associated parameters, and from the practical case example demonstrated in this paper, it is obvious that some conclusions useful for interpreting the results are helpful. The validity of the conclusion is assisted by the empirical data that are used to test the model. The future holds much promising results in the improvements of the existing model. The application of hybrids of genetic algorithms and artificial neural networks, genetic algorithm and fuzzy logic will open a new stream of research that would engage researchers for several decades to come.

References

1. Cronin, K., Fitzpatrick, J., McCarthy, C. (2003). "Packaging strategies to counteract weight variability in extruded food products", *Journal of Food Engineering*, **56**(4), 353-360.
2. Garbriele, D., Curcio, S., Cindio, B., (2001). "Optimal design of single-screw extruder for liquorice candy production: a rheology based approach", *Journal of Food Engineering*, **48**(1), 33-44.
3. Gouindasamy, S., Campanella, O.H., Oates, C.G. (1997). "The single screw extruder as a biorector for sago starch hydrolysis". *Food Chemistry*, **60**(1), 1-11.
4. Heinzel, G.; Freise, A.; Grote, H.; Strain, K and Danzamann, K. (2002). "Dual recycling for GEO 600", *Classical and Quantum Gravity*, **19**(7), 1547-1553.
5. Goulias D.G. (2001). "Durability evaluation of asphalt mixtures modified with recycled tire rubber", *Journal of Solid Waste Technology and Management*, **27**(3&4) muse.wider.edu/~sxw0004/cumindex.html
6. Goulias D.G. (2001). "Reinforced recycled polymer based composites for highway poles". *Journal of Solid Waste Technology and Management*, **27**(2) muse.wider.edu/~sxw0004/cumindex.html
7. Treloar, G.J., Gupta, H., Love, P.E.D and Nguve, B. (2003). "An analysis of factors influencing waste minimization and use of recycled materials for the construction of residential building", *Management of Environmental Quality: An International Journal*, **14**(1), 134-145.
8. Curlee T.R., and Das S. (1998). "The viability of recycling plastic by tertiary processes". *Journal of Solid Waste Technology and Management*,**25**(3,4) muse.wider.edu/~sxw0004/cumindex.html
9. Kumaran, D.S., Ong. S.K., Tan, R.B.H. and Nee, A.Y.C. (2001). "Environmental lifecycle cost analysis of products", *Environmental Management and Health*, **12**(3), 260-276.
10. Feiock, R.C. and Kalan, L.G. (1999). "Assessing the performance of solid waste recycling programs over time", *American Review of Public Administration*, **31**(1), 22-32.
11. Fullerton, D. and Kinnaman, T.C. (1995). "Garbage, recycling and illicit burning or dumping", *Journal of Environmental Economics and Management*, **29**, 78-91.
12. Fullerton, D. and Kinnaman, T.C. (2000). "Garbage and recycling with endogenous local policy", *Journal of Urban Economics*, **48**, 419-442. muse.wider.edu/~sxw0004/cumindex.html
13. Grote, H.; Freise, A.; Malec, M.; Heinzel, G.; Willke, B.; Luck, H.; Strain, K.A.; Hough, J. and Danzmann, K. (2004). "Dual Recycling for GEO 600" *Classical and Quantum Gravity*, **21**(5), S473-S480.
14. Guha, M., Ali, S.Z., Bhattacharya, S. (2003). "Screening of variables for extrusion of rice flour employing a placket-Burman design", *Journal of Food Engineering*, **57**(2), 135-144.
15. Kimbrough D.E., Wong P.W., Biscoe J., Kim J. (1996). "A critical review of photographic and radiographic silver recycling", *Journal of Solid Waste Technology and Management*, vol. **23**(4), muse.wider.edu/~sxw0004/cumindex.html
16. Malec, M.;Grote, H.; Freise, A.; Heinzel, G.; Strain, K.A.; Hough, J. and Danzmann, K. (2004). "Towards dual recycling with the aid of time and frequency domain simulations", *Classical and Quantum Gravity*, **21**(5), S991-S998.