AN EXERGY ANALYSIS IN A MIXED FEED INDUSTRY: EVALUATION OF AN EXTRUDER PELLET LINE

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***Abstract**: The mixed feed sector is one of the most important agricultural sectors in Turkey, with 506 factories at capacities varying from 0.8 to 60 ton/h. In the literature, there are very limited studies on the energy and exergy analysis of mixed feed industries and the extruder pellet line used in the mixed feed factories.*

In this study, an exergy analysis of an extruder pellet line, which is currently available only in the three factories in the country, in a mixed feed factory located in Izmir, Turkey was performed. The results obtained were evaluated and discussed.

Key words: *Energy Efficiency, Exergy Analysis, Extruder Pellet Line, Mixed Feed Sector, Turkey*

1. INTRODUCTION

Historically, the agriculture sector has been Turkey's largest employer and a major contributor to the country's gross national product (GNP), exports and industrial growth. However, as the country developed, share of the agriculture has declined in importance relative to the rapidly growing industry and services sectors. Due to the export oriented industrialization policy, rapid growth has been substantial development in the agriculture sector based industrial sectors. Beside this, agricultural potential has not been fully realized nationwide. Despite agriculture's diminished role in Turkish economy, agriculture still accounts for a large share of total output and employment [1].

Energy efficiency in feed mills has increased significantly since the mid-1980s. Over the same period, however, feed compounders have developed products requiring more energy-intensive processing. In this regard, energy efficiency pelleting remains critically important, especially as margins on livestock and poultry feeds have become very narrow [2]. Among the most important inputs to the animal feeding are several kinds of mixed feeds, which are met by three different ways, namely: (a) their own small-scale mixed feed plant, (b) private small-scale mixed feed plant companies, and (c) mixed feed factories. In the recent years, the demand on the mixed feeds has increased significantly [3].

In 1999, there were 486 mixed feed factories with a total production capacity of 11 724 000 tonnes annually in Turkey. Of these, 90 factories already stopped their productions due to several reasons, such as wrong marketing policies, the fluctuations in the animal production, etc. The mixed feed production was determined to be 6 046 106 tonnes by the Feed Manufacturers' Association, representing a partial capacity of 59.2% with 396 mixed feed factories [4]. The distribution of the Turkish feed factories is illustrated in Table 1, where the total number of the feed factories reached 486 in 1999 to 506 in 2000. The capacities of the mixed feed factories range from 0.8 to 60 ton/h [5]. There are two factories with a maximum capacity of 60 t/h, located in the Marmara and Southeast Anatolia regions of the country. The most important demand on the mixed feed results from cattle and sheep, goat farms. Therefore, some effective activities should be done for operating these factories at the full load and efficiently in Turkey.

The idea of exergy has been the object of renewed interest as energy has become more and more a critical factor in industrial economics [6]. Little application of exergy analysis has been made to the agricultural industries although the concept exergy is not new and was already known in the past century. In this regard, this study presents an exergy analysis of a pellet line in a Turkish mixed feed factory.

Table 1. Distribution of Turkish feed factories by regional as of end of 2000 [5]

Region	Number of feed factories	Average capacity (ton/h)	Total capacity (ton/h)	Feed factories not in operation			
				No.	Average capacity (ton/h)	Total capacity (ton/h)	% of total feed factories
Marmara	111	13.9	1546	24	8.8	212	22
Aegean	77	12.5	960	15	7.0	105	15
Mediterranean	50	11.2	561	14	7.9	110	10
Central Anatolia	129	12.1	1559	18	7.9	142	25
Black Sea	64	10.8	692	10	6.2	62	13
East Anatolia	37	10.4	384	4	7.5	30	7
Southeast Anatolia	38	11.3	428	6	13.0	78	8
Total	506	12.1	6130	91	8.1	739	100

2. ENERGY AND EXERGY

During the past two decades, increasing energy prices and environmental impact have brought the energy issues to the forefront and considerable attention has been paid to efficient energy utilization and process improvement studies and programs. This leads to an accurate thermodynamic analysis of thermal systems for design and optimization purposes. In this context, two essential tools, namely energy analysis (referring to the first law thermodynamics; FLT) and exergy analysis (referring to the second law of thermodynamics; SLT), may be used [7]. In recent years, exergy analysis has played a key role in order to evaluate processes by taking into account not only the quantity of energy but also both the quantity and quality of energy.

In the literature [8-11], various definitions have been used to describe the term of exergy. Table 2 shows a comparison between energy and exergy [7]. Exergy is defined as the maximum amount work which can be produced by a system or a flow of matter or energy. Exergy is a measure of the potential of the system or flow to cause change, as a consequence of not being completely in stable equilibrium relative to the reference environment. Unlike energy, exergy is not a subject to a conservation law (except for ideal, or reversible processes). Rather exergy is consumed or destroyed due to irreversibilities in any real process. The exergy consumption during a process is proportional to the entropy created due to irreversibilities associated with the process [12].

Table 2. Comparison between energy and exergy [7]

Energy	Exergy
It is dependent on the parameters of matter or energy flow only, and independent of the environmental parameters.	It is dependent both on the parameters of matter or energy flow and on the environmental parameters.
It has the values different from zero (which equal to mc^2 in accordance with Einstein's equation).	It is equal zero (in dead state by equilibrium with the environment).
It is guided by the FLT for all processes.	It is guided by the FLT for reversible processes only (in irreversible processes it is destroyed partly or completely).
It is limited by the SLT for all processes.	It is not limited for reversible processes owing to the SLT.

3. EXERGY ANALYSIS OF THE PELLET LINE

3.1. DESCRIPTION OF THE EXTRUDER PELLET LINE

In the plant selected as an application place, 226 kinds of mixed feeds in various forms and varieties are processed in six production lines with two different raw material inputs for domestic animals. Of the total feed production, on average, pellet accounts for 45.1%, followed by extruder pellet at 16.8%, granule at 15.9%, mash at 16.8%, and micron extruder pellet at 5.3%. The animals are as follows: ruminant as dairy and beef cattle, sheep and goat, ostrich, poultry as layer hen and broiler, turkey, duck, partridge, pheasant, quail etc., aquaculture as reinbow trout, seabream, mullet, sea bass, common carp, and shirmp.

In 1999, the share of the ruminant feed in the total feed production was 45%, followed by the poultry feed at 32%, and the aquaculture feed 23%. In 2000, the ruminant mixed feed production decreased from 45% to 43%, while the poultry feed remained at the same level and the aquaculture feed increased from 23% to 25%. As of September 2001, the ruminant feed accounted for 37%, followed by the poultry feed 34%, and the aquaculture feed at 29% [13].

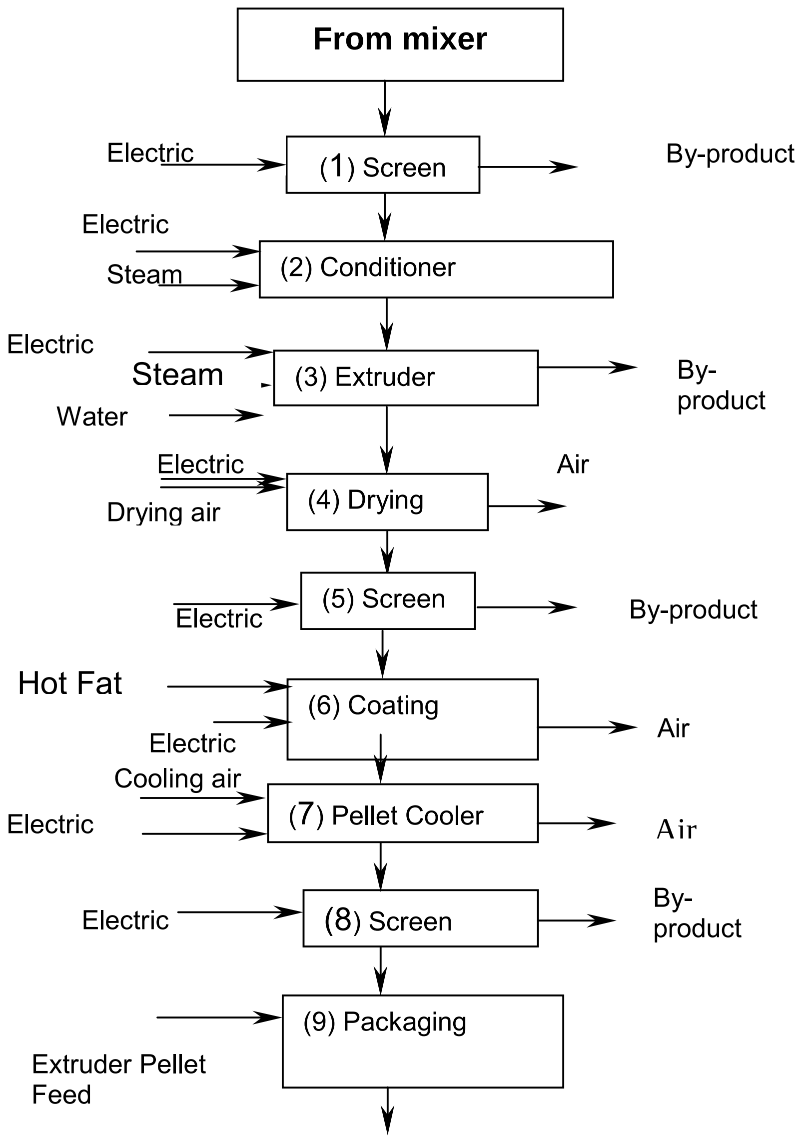

Figure 1. A schematic of the pellet line studied

Figure 1 illustrates a flow diagram of the pellet line studied. The exergy analysis of the mixed feed factory was limited to the pellet line, while a schematic of the whole system was given elsewhere [13]. The pellet line begins with the mixing process and ends with the packaging. It also includes some processes, such as extruder, drying and cooling, which use especially steam, water, air and electric.

3.2. TEORETICAL ANALYSIS

Exergy analysis is a method using the conservation of mass and conversion of energy principles together with the second law of thermodynamics for the analysis, design and improvement of energy and other systems [12]. An exergy balance applied to a process or a whole plant tells us how much of the usable work potential, or exergy, supplied as the input to the system under consideration has been consumed by the process. The loss of exergy, or irreversibility, provides a generally applicable quantitative measure of process inefficiency [9]. In other words, an exergy analysis is similar to an energy analysis, but takes into account the quality of the energy as well as the quantity. Since it includes a consideration of entropy, exergy analysis allows a system to be analyzed more comprehensively by determining where in the system the exergy is destroyed by internal irreversibilities, and the causes of those irreversibilities [14].

For each process in the pellet line, the following equations are applied to find the rate of irreversibility [15]:

Exergy balance for any system undergoing any process can be expressed as:

(Total exergy entering) - (Total exergy leaving) – (Total exergy destroyed) = (Change in the total exergy of the system) (1a)

or

$$X_{in} - X_{out} - X_{destroyed} = \Delta X_{system} \tag{1b}$$

Negleting the potential and kinetic terms, the exergies of a fixed mass (nonflow energy), ϕ and a flow stream, ψ are expressed by the equations

$$\phi = (U-U_0) + P_0 (V-V_0) - T_0 (S-S_0) \tag{2}$$

and

$$\psi = (H-H_0) - T_0 (S-S_0) \tag{3}$$

where subscript zero denotes the properties of a system at the dead state.

The difference between the reversible work and the useful work is due to the irreversibilities and is called the irreversibility (I). It is equivalent to the exergy destroyed and is expresed as:

$$I = X_{destroyed} = T_0 S_{gen} \tag{4}$$

where S_0 is the entropy generated during the process.

Inefficiency can aslo be defined as the ratio of the irreversibilty in each section to the irreversibility over all sections (total irreversibility).

Table 3. Exergy balance of the pellet line studied

Pro. no.	Description of process	Electricity used kW	Inlet streams Items	Mass flow rate kg/h	Temp.(^{o}C)/ humidity ω or x [a]	Outlet streams Items	Mass Flow rate kg/h	Temp.(^{o}C)/ humidity ω or x [a]	$X_{destroyed}$ (or I) kJ/h	S_{gen} kJ/hK	Inefficiency %
1	Screen	2.01	Feed	4602	8	Feed By-product	4556 46	8 8			
2	Conditioner	13.9	Feed Steam	3200 25	8 170	Conditioned feed	3225	44	18820.75	65.35	5.98
3	Extruder	192.94	Feed Water Steam	3225 360 195	44 25 170	Feed By-product	3653 127	98 44	59346.60	199.15	18.87
4	Dryer	46.56	Hot air Feed	13155 3653	110/ ω=0.005 90/ x= 0.21	Cold air Dried feed	13155 3251	26/ ω=0.0389 40/ x=0.10	213778.10	717.38	67.97
5	Screen	0.75	0.75	3251	40	Feed	3219	40			
6	Coating	26.62	Feed Hot fat	3219 644	40/ x=0.10 62	Coated feed	3863	41	20075.60	63.37	6.38
7	Pellet Cooler	21.37	Feed Air	3863 18496	41/ x=0.10 8/ ω=0.0047	Pelleted feed Air	3785 18496	18/ x=0.09 15/ ω=0.0022	2495.72	8.37	0.80
8	Screen	1.30	Feed	3785	18/ x=0.09	Feed By-product	3748 37	18/ x=0.09 18			
TOTAL									314516.77	1053.7	100.00

[a] ω indicates the absolute or specific humidity, also called humidity ratio (kg water vapor/kg dry air), while x denotes the material moisture content on the basis of dry material.

The moisture content of the air changes during the process under consideration, the influence of the moisture on the exergy cannot be neglected. In this regard, the thermal exergy of humid air may be calculated using equations given elsewhere [10,16].

3.3. EVALUATION OF RESULTS

In the exergy analysis, the dead-state temperature and pressure were assumed to be T_0= 25^{o}C and P_0 = 101.325 kPa, respectively, while the useful works were not taken into account. The results obtained are summarized in Table 3. It is clear from this table that the dryer accounted for round 68% of the losses, followed by extruder with 19, totalling both 87% of the losses.

4. CONCLUSIONS AND FUTURE WORK

In the literature, there are very limited studies on the exergy analysis of the extruder pellet line. In this regard, the present study indicates the fact that exergy balance is a powerful diagnostic tool for energy use optimization. In other words, exergy analysis can reveal whether or not and by how much it is possible to design more efficient energy systems by reducing the inefficiencies in existing systems. Many engineers and scientists suggest that the thermodynamic performance of a process is best evaluated by performing an exergy analysis because exergy analysis appears to provide more insights and to be more useful in efficiency improvement efforts than energy analysis, as emphasized by Rosen and Dincer [12].

The exergy analysis presented here should be evaluated a preliminary study of the pellet line. Nevertheless, it is necessary to perform further and detailed analyses and calculations including the remaining parts of the plant studied.

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