Energy generation power: an example of research concerning industrial waste as fuel in furniture industries used in practical classes at a mechanical engineering course

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Abstract – *Furniture industries waste could be used as fuel to co-generation of heat and power in order to minimize its disposal on the environment and environmental impact as well. Research involving 95 enterprises of different sizes and product types was made in the mountain region of Rio Grande do Sul State, Brazil. A division was made in four segments: wood (21 enterprises), particle board (27 enterprises), MDF (Medium Density Fiber) (33 enterprises) and plywood (13 enterprises). For each segment it was analyzed the waste generation over unities of mass and energy consumed, total (kWh) and specific (kWh/m3). The investigation shows that, according to the raw material employed, the energy production percentage could vary as follows: MDF – 85.7%; wood – 70.5%; particle board - 48.7% and plywood – 19.1%. The potentials show that enterprises, in average, are not high electrical energy consumers. The economic interest of enterprises was analyzed as well. This research was used in practical classes of the Mechanical Engineering Course of the Pontifícia Universidade Católica do Rio Grande do Sul (PUCRS) and Universidade de Caxias do Sul (UCS), Rio Grande do Sul, Brazil. The pedagogic procedure involved resources of SPSS statistical software, power point and data show. The objective was offer sbsidies to the students for critical analyses over real data. Frequencies, percents, cross tables, analysis of variance, correlations and regressions were also used to enrich the analyses. The students grades were considered excellent*

Keywords: wood waste, gasification process, power generation, industrial waste use, statistical analyses.

Introduction

Residues from the furniture industry can be used as fuel for co-generation of heat and power, minimising its disposal on the environment and consequently reducing its environmental impact. A research involving 95 companies of various sizes and kinds of products was carried out in the highland region of Rio Grande do Sul state, Brazil. Companies were divided according to the industry segment and main raw material employed: wood (21 companies), particle board (27 companies), MDF (Medium Density Fibre) (33 companies) and plywood (13 companies). This research was used on practical classes for engineering courses of the Pontifícia Universidade Católica of Rio Grande do Sul, PUCRS, and Universidade de Caxias do Sul, UCS, Rio Grande do Sul, Brazil. The pedagogical procedure involved statistical resources from SPSS software, and also Power Point and Data Show. The aim was to offer the students subsidies to establish a critical analysis on real data. For data analyses were employed frequencies, percentages, cross tables, analysis of variance (ANOVA), correlations and regressions.

Characteristics of the residues generation by the furniture industry.

On north eastern region of Rio Grande do Sul state, Brazil, the most common economical use given to wood waste is the sale of shavings to aviaries. The use of this kind of waste for power generation would be an interesting application since most of the companies are small and thus a solution for power generation in terms of equipment can be simple and at a relatively low cost.

Reference [1] presents a study done on a city of this north eastern region of this state, confirming a wood waste excess being incorrectly disposed of. Unused wood waste could cause serious environmental problems, especially silting up of brooks and small rivers.

For the furniture industries, an alternative for electricity would be through the gasification process, in which the fuel gas produced can be burned in an internal combustion motor. These motors are more adequate given their higher efficiency on small scales, and the use of fuel gases of low energy content does not significantly compromise performance, once care is taken.

The concept of small gasification units found in the literature is much more diversified than the values considered adequate to stimulate the self energy production from waste. However, the manual published by the *Biomass Energy Foundation Press* [2] is considered a guide for projects of small scale gasification systems (mechanical power up to 200 kW).

The main reactions occurring simultaneously in a biomass gasifier are pirolysis, combustion and gasification. The latter converts 60 to 90% of the energy contained in biomass to energy contained in the fuel gas produced. In general, ambient air is used as the gasifying agent, however in subestequiometric quantities. The main advantages of biomass are: low cost, low amount of ash and sulphur and the lack of CO_2 level increase in the atmosphere, as long as the produced amount does not exceeds the CO_2 consumed during forest growth.

On reference [3], various aspects of the gasification units for wood waste to co-generate heat and power are presented, from gasification principles to economic aspects of gasification installations integrated to combustion motors. Based on this study, gasifiers on fixed grate, descending flow, stratified and open top are the ones producing the lower levels of tar.

Other authors [4][5][6][7][8][9] also treat small gasifiers, showing experimental study results gasifying different kinds of biomass, especially rice skin and wood waste in the form of small pellets. All these studies used the descending current gasifier since it produces less tar, reaching levels low enough so that internal combustion motors could be used without problems as wear and tear and malfunctioning.

Based on the data found in [10] the potential for power generation with waste from the furniture industry can be evaluated, in spite of necessary simplifications and considering performance of equipment not yet under study.

Gasification Studies

Given the use of a wood waste gasifier [10], with values of gas flow rate, efficiency and heating power obtained and estimating the efficiency of the generator group in 30%, the potential for using waste from industries of the furniture sector was evaluated. The main result is the index relating dry waste needed per kWh, which reached practically 1 kg of dry wood waste for each kWh electrical power produced. During tests of the equipment operational and materials aspects were also evaluated and problems that must be solved before operation in commercial scale were detected. The main problems are internal agitation to avoid empty spaces, grate operation to control solid flow rate and material wear due to high temperatures obtained.

Applying these results to the evaluated industries the energy generation potential from waste produced can be assessed. Table 1 shows values for waste generation and energy needs, as well as percent energy needed waste can fulfil and average power for a 12 h operation days.

Table 1 – Waste Generation and Energetic Needs

Raw material	Waste [kg/day]	Energy [kWh/day]	Production [%]	POT [kW]
Wood	1817,7	2580,1	70,5	218,3
Particle board	2740,7	5625,5	48,7	476,0
MDF	1442,1	1683,0	85,7	142,4
Plywood	96,8	506,0	19,1	42,8

The powers determined prove that companies, on average, are not large consumers of electric energy. No industry segment can produce all its electric energy from waste, since most receive already beneficed wood. Despite that, there is a reasonable capacity for energy generation in this sector and not reaching self sufficiency is not a problem because the distribution structure already existent can be maintained by the power utility as supply guarantee using waste to complement energetic needs and optimising installations. The main difficulties in using wood waste as a power source are its form and humidity. In furniture companies the raw material is already dry and thus, the problem drying the fuel can be discarded.

A research

An extensive work of data gathering was done analysing 94 companies of various sizes and kinds of products. A division into four segments was made according to the main raw material employed: wood (21 companies), particle board (27 companies), MDF (33 companies) and plywood (13 companies). For each segment waste generation was studied in mass units and total (kWh) and specific (kWh/m^3) consumed energy were also evaluated. The destination of wood waste was also monitored to guarantee the interest the company would have in using it as a power source.

Regarding form, waste was divided in three main types: sawdust, shavings and scraps. Among these, sawdust presents most difficulties for its use, needing special equipment or else having to be transformed in pellets, small uniform pieces, generally cylindrical.

Results from waste generation were varied with companies using mostly wood and MDF generating mainly sawdust (respectively 42.9 and 52.9% of generated waste) and companies using mostly particle board and plywood generating mainly scraps (respectively 63.7 and 61.5% of generated waste) and not much shavings (4.8% for both).

Regarding total and specific energy spending, Table 2 shows the average for each segment.

Table 2 –Total and Specific Energy Spending

Type of raw material	Total Energy [MWh/month]	Specific Spending [kWh/m^3]
Wood	56,8	230,6
Particle board	123,8	86,2
MDF	35,9	125,1
Plywood	11,1	158,6

To calculate the average specific energy spending the extreme values were discarded. However, these data do not reveal the diversity of companies concerning production and energy spending characteristics for activities not directly connected to wood processing, serving only as an indication.

Considerations of the research

Of the 94 companies evaluated, it is important to mention that only a third (32) would need an installed power source of more than 70 kW based on the energy consumed in a month divided by 260 hours (approximately 12 hours a day, 5 days a week).

Presently, the fate of the waste for a furniture company is divided into five possibilities: burning, donation, selling, filling with earth and reusing, and the vast majority of the companies adopts one or two of these possibilities. It can be considered that companies that burn, donate or send waste for filling up with earth would be better off economically in waste use. Thus, considering those that nowadays adopt more than 50% of one of these three possibilities, nine companies burn, 41 companies donate and six companies send waste to be filled with earth. Of the latter, five companies are small, with up to five employees and low waste production. For the other waste destination possibilities, 32 companies sell more than 50% and five reuse more than 50% of the waste. Only nine reuse waste, and of these, eight sell what they do not reuse and one donates 7% of the produced waste.

Concluding, generation of power by the furniture industries can be an opportunity for optimisation of the installations and higher competitivity because of the possibility of reducing energy costs and waste disposal. In three segments power generation potential is practically half the needs of the companies.

It is important to emphasise the need to choose adequate technology, with good relationship between efficiency and cost, and also to ensure the chosen technology does not generate undesired environmental impacts. With the technology presented here the main environmental aspects to be observed are gaseous emissions from the internal combustion motor and liquid effluents for cleaning the gas produced.

Academic results analysis

The general results from this study were made available to the industries involved and to other interested parts.

Additionally, the research was used in classes of engineering courses with the aim to offer students with an example of quantitative analysis on real data and of regional interest. Below a resume of the pedagogic methodology used is presented. In a computer lab the resources used were SPSS statistical software version 11.5 and data-show presentations.

The main variables involved were classified in categorical and numeric.

The categorical ones are: production line (serial, on demand or both) and raw material produced (wood, particle board, MDF or plywood).

The numeric ones are:

1st group – waste production: sawdust, shavings, scraps, total production and total waste. These variables were measured in m^3/month and later transformed to kg.

2nd group – consumption: total spending (kWh/month), specific spending (kWh/m^3) and specific waste (kg/month).

3rd group – categorised numeric variables: total production, total waste, specific consumption and specific waste were categorised so as to use analysis by crossing factors.

Below are the variables, categoric ones with categorical frequencies and numeric ones with averages and standard deviations. (See annex)

From the presentation of the first outputs, stimulated and oriented by the lecturers, the students started to offer observations and criticism. Many questions were raised from the variables involved and according to objectives proposed.

Initially, the aim was to know whether company production and consumption were significantly different according to raw material produced. Analysis of variance and regression are immediately suggested. However, it is nearly impossible to use these analyses given the enormous variability in production and consumption among companies, as can be observed in the tables below (see annex).

Thus, it is demonstrated that in this case analyses need to be done by crossing, using the categorised numeric variables. In consequence, crossing analyses were performed, with the respective significance tests and contingence coefficients, as below:

Crossing 1: categorised total production X raw material (see annex).

Crossing 2: categorized total waste X raw material (see annex).

Crossing 3: categorised specific waste X raw material (see annex).

Crossings suggested further analyses. For example, it can be observed that the majority of the companies makes furniture in series from Particle board or MDF. It can also be seen that the largest companies use particle board and MDF as raw material, whilst the smallest use MDF and Wood. Analysing the crossing of categorised specific waste, which is independent of the size of the company, with kind of raw material used, it is observed that companies using particle board generate less waste, whilst those using MDF generate more waste to produce a given amount of product.

Bivariate correlations were also analysed, involving variables total production, total waste, total consumption, specific consumption and specific waste. The result suggest a richness of analyses and interpretations, as, for example, showing that larger companies have a significantly lower ($p < 0{,}05$) specific waste, and despite specific consumption also decreasing with company size, this correlation is not significant ($p > 0{,}05$) (see annex).

All tables raised rich interpretations among students, indicating new analyses, with an excellent pedagogic benefit from this exercise, which reached its objectives fully.

Annex

Line tipe

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	In serie	56	59,6	59,6	59,6
	By mesure	30	31,9	31,9	91,5
	Both	8	8,5	8,5	100,0
	Total	94	100,0	100,0	

Raw material

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Wood	21	22,3	22,3	22,3
	Particleboard	27	28,7	28,7	51,1
	MDF (Medium Density Fiber)	33	35,1	35,1	86,2
	Plywood	13	13,8	13,8	100,0
	Total	94	100,0	100,0	

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Sawdust kg	94	,00	449345,0	14686,09	51972,71
Sharings kg	94	,00	189410,0	5077,320	24625,83
Scraps kg	94	,00	526500,0	16543,48	60209,74
Total production in kg	94	,98	10200,00	617,7159	1573,017
Total waste kg	94	,00	773755,0	36306,90	110554,1
Valid N (listwise)	94				

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Total consumption kWh/month	93	100,00	750000,0	57841,61	137856,5
Specific consumption kWh/m3	94	,30	3254,40	195,0606	362,16136
Specific waste kg/m3	94	,00	1128,06	165,6632	195,01998
Valid N (listwise)	93				

Report

Specific consumption kWh/m3

Raw material	Mean	N	Std. Deviation
Wood	374,6286	21	677,49961
Particleboard	104,5852	27	124,70379
MDF (Medium Density Fiber)	145,1182	33	150,22721
Plywood	219,6769	13	274,31629
Total	195,0606	94	362,16136

Report

Specific waste kg/m3

Raw material	Mean	N	Std. Deviation
Wood	207,9250	21	260,14245
Particleboard	79,2698	27	84,36084
MDF (Medium Density Fiber)	201,6422	33	204,45821
Plywood	185,4955	13	176,53362
Total	165,6632	94	195,01998

Categorized specific consumption kWh/m3

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	lowest throug100	44	46,8	46,8	46,8
	100 throug 200	24	25,5	25,5	72,3
	200 throug 300	11	11,7	11,7	84,0
	300 throug 500	9	9,6	9,6	93,6
	500 throug highest	6	6,4	6,4	100,0
	Total	94	100,0	100,0	

Categorized specific waste kg/m3

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	lowest throug 50	26	27,7	27,7	27,7
	50 throug 100	20	21,3	21,3	48,9
	100 throug 200	22	23,4	23,4	72,3
	200 throug 500	19	20,2	20,2	92,6
	500 through highest	7	7,4	7,4	100,0
	Total	94	100,0	100,0	

Categorized total production kg

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	lowest throug 10	28	29,8	29,8	29,8
	10 throug 100	32	34,0	34,0	63,8
	100 through 1000	18	19,1	19,1	83,0
	1000 through 5000	14	14,9	14,9	97,9
	5000 through highest	2	2,1	2,1	100,0
	Total	94	100,0	100,0	

Categorized total waste kg

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	lowest through 1000	24	25,5	25,5	25,5
	1000 through 5000	30	31,9	31,9	57,4
	5000 through 20000	19	20,2	20,2	77,7
	20000 through 100000	13	13,8	13,8	91,5
	100000 throug highest	8	8,5	8,5	100,0
	Total	94	100,0	100,0	

Categorized total production kg * Raw material Crosstabulation

			Raw material				Total
			Wood	Particleboard	MDF (Medium Density Fiber)	Plywood	
Categorized total production kg	lowest throug 10	Count	6	2	15	5	28
		% within Categorized total production kg	21,4%	7,1%	53,6%	17,9%	100,0%
	10 throug 100	Count	9	9	7	7	32
		% within Categorized total production kg	28,1%	28,1%	21,9%	21,9%	100,0%
	100 through 1000	Count	4	7	7	0	18
		% within Categorized total production kg	22,2%	38,9%	38,9%	,0%	100,0%
	1000 through 5000	Count	2	7	4	1	14
		% within Categorized total production kg	14,3%	50,0%	28,6%	7,1%	100,0%
	5000 through highest	Count	0	2	0	0	2
		% within Categorized total production kg	,0%	100,0%	,0%	,0%	100,0%
Total		Count	21	27	33	13	94
		% within Categorized total production kg	22,3%	28,7%	35,1%	13,8%	100,0%

Fisher Exact Test p=0.017

Categorized specific consumption kWh/m3 * Raw material Crosstabulation

			Raw material				Total
			Wood	Particleboard	MDF (Medium Density Fiber)	Plywood	
Categorized specific consumption kWh/m3	lowest throug100	Count	2	18	17	7	44
		% within Categorized specific consumption kWh/m3	4,5%	40,9%	38,6%	15,9%	100,0%
	100 throug 200	Count	8	6	8	2	24
		% within Categorized specific consumption kWh/m3	33,3%	25,0%	33,3%	8,3%	100,0%
	200 throug 300	Count	5	0	5	1	11
		% within Categorized specific consumption kWh/m3	45,5%	,0%	45,5%	9,1%	100,0%
	300 throug 500	Count	4	2	2	1	9
		% within Categorized specific consumption kWh/m3	44,4%	22,2%	22,2%	11,1%	100,0%
	500 throug highest	Count	2	1	1	2	6
		% within Categorized specific consumption kWh/m3	33,3%	16,7%	16,7%	33,3%	100,0%
Total		Count	21	27	33	13	94
		% within Categorized specific consumption kWh/m3	22,3%	28,7%	35,1%	13,8%	100,0%

Fisher Exact Test p=0.006

Categorized total waste kg * Raw material Crosstabulation

			Raw material				Total
			Wood	Particleboard	MDF (Medium Density Fiber)	Plywood	
Categorized total waste kg	lowest through 1000	Count	5	3	9	7	24
		% within Categorized total waste kg	20,8%	12,5%	37,5%	29,2%	100,0%
	1000 through 5000	Count	7	8	10	5	30
		% within Categorized total waste kg	23,3%	26,7%	33,3%	16,7%	100,0%
	5000 through 20000	Count	3	5	10	1	19
		% within Categorized total waste kg	15,8%	26,3%	52,6%	5,3%	100,0%
	20000 through 100000	Count	3	7	3	0	13
		% within Categorized total waste kg	23,1%	53,8%	23,1%	,0%	100,0%
	100000 throug highest	Count	3	4	1	0	8
		% within Categorized total waste kg	37,5%	50,0%	12,5%	,0%	100,0%
Total		Count	21	27	33	13	94
		% within Categorized total waste kg	22,3%	28,7%	35,1%	13,8%	100,0%

Fisher Exact Test p=0.109

Categorized specific waste kg/m3 * Raw material Crosstabulation

			Raw material				Total
			Wood	Particleboard	MDF (Medium Density Fiber)	Plywood	
Categorized specific waste kg/m3	lowest throug 50	Count	4	11	8	3	26
		% within Categorized specific waste kg/m3	15,4%	42,3%	30,8%	11,5%	100,0%
	50 throug 100	Count	6	9	5	0	20
		% within Categorized specific waste kg/m3	30,0%	45,0%	25,0%	,0%	100,0%
	100 throug 200	Count	3	5	8	6	22
		% within Categorized specific waste kg/m3	13,6%	22,7%	36,4%	27,3%	100,0%
	200 throug 500	Count	6	2	9	2	19
		% within Categorized specific waste kg/m3	31,6%	10,5%	47,4%	10,5%	100,0%
	500 through highest	Count	2	0	3	2	7
		% within Categorized specific waste kg/m3	28,6%	,0%	42,9%	28,6%	100,0%
Total		Count	21	27	33	13	94
		% within Categorized specific waste kg/m3	22,3%	28,7%	35,1%	13,8%	100,0%

Fisher Exact Test p=0.054

Correlations

		Total production in kg	Total waste kg	Total consumption kWh/month	Specific consumption kWh/m3	Specific waste kg/m3
Total production in kg	Pearson Correlation	1	,564**	,614**	-,106	-,218*
	Sig. (2-tailed)	.	,000	,000	,310	,035
	N	94	94	93	94	94
Total waste kg	Pearson Correlation	,564**	1	,637**	-,049	-,041
	Sig. (2-tailed)	,000	.	,000	,640	,693
	N	94	94	93	94	94
Total consumption kWh/month	Pearson Correlation	,614**	,637**	1	,027	-,175
	Sig. (2-tailed)	,000	,000	.	,796	,093
	N	93	93	93	93	93
Specific consumption kWh/m3	Pearson Correlation	-,106	-,049	,027	1	,085
	Sig. (2-tailed)	,310	,640	,796	.	,414
	N	94	94	93	94	94
Specific waste kg/m3	Pearson Correlation	-,218*	-,041	-,175	,085	1
	Sig. (2-tailed)	,035	,693	,093	,414	.
	N	94	94	93	94	94

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

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