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Recovery of aluminium from multi-component packaging using a fluidised bed reactor

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This study presents the use of fluidised bed combustion to produce thermal energy, aluminium recovery and the reduction of the Tetra Pak and Combibloc packaging waste stream. Fluidisation and the pneumatic transport, which take place in the same apparatus, allow recovering bits of the aluminium foil from the combustion zone. The limited time spent in the high temperature zone leads to a high content of free metal in the solids separated in the ash trap and cyclone. Other solid products are practically chemically inert and may be disposed in a landfill of municipal or inert wastes.

Keywords: fluidisation, combustion, multilayer packaging, thermal energy, recovery of aluminium.

INTRODUCTION

Thermal engineering is widely applied in the economy and has recently shown a growing and significant meaning in the process of converting various waste materials. Of many types of wastes, of which processing becomes a necessity, Tetra Pak and Combibloc were chosen. Both of them are used to store liquid food and their utilization is still an issue that has not been globally resolved, yet. Such waste cannot be added to wastepaper during the process of segregation because it contains aluminium foil. Thus, it is usually stored in landfills. It is possible to use it as a substitute fuel as a source of thermal energy and also as a source of aluminium and aluminium oxides.

Nowadays, multilayer packaging is not separated from the waste stream although it is possible because it is easily identified. However, this situation can change if a proper technology to neutralise it has been developed.

The material used to make such multi-layer packaging is the composite made from a thin layer of chalked cardboard printed on one side and coated on both sides with a polymer, usually polyethylene[1]. The inner layer of the cardboard is additionally covered with aluminium foil. The composite is made in such a way so as to avoid stratification. Thus mechanical methods of decomposing the material cannot be applied and because the material is coated on both sides with polyolefin, decomposition using solutions is also impossible.

The multilayer composite doesn't consist of elements like F, Cl, Br, S, N, P and heavy metals. It is mostly made of C, H, O and Al. Table 1 presents the packages' composition. Based on chemical analysis the mass fraction in the packages' composition of coal, hydrogen and oxygen is: 49.28; 7.32; 35.71% respectively.

EXPERIMENTAL

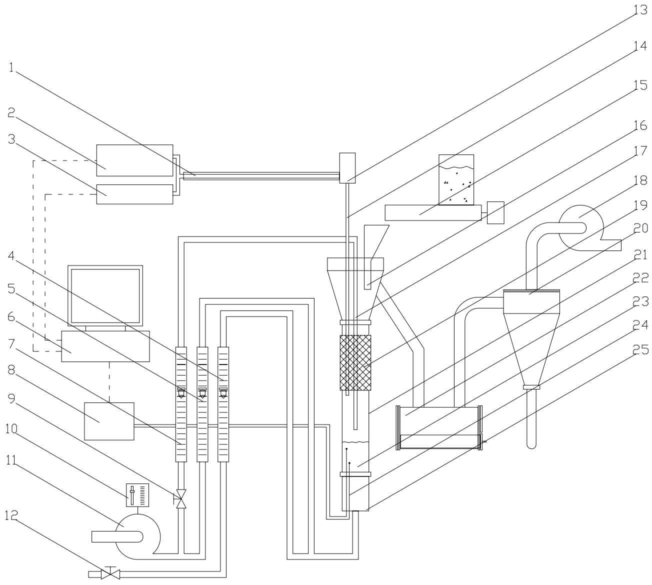

Figure 1. A Laboratory Installation Scheme: 1 – heated pipe for sampling flue gases, 2 – analyser apparatus MRU, 3 – analyser apparatus JUM, 4 – gas rotameter, 5 – primary air rotameter, 6 – data collection apparatus, 7 – secondary air rotameter, 8 – processor A/C, 9 – secondary air regulation valve, 10 – air blower control system, 11 – air blower, 12 – gas regulation valve, 13 – probe filter, 14 – probe for sampling flue gases, 15 – feeder, 16 – feeder tube, 17 – secondary air pipe, 18 – exhaust blower, 19 – movable radiation shield, 20 – cyclone, 21 – quartz pipe, 22 – ash trap, 23 – sand bed, 24 – thermocouples, 25 – plenum chamber

Packages were subjected to thermal decomposition inside a fluidised bed reactor (Figure 1). The bed consisted of sand at the granulation of 0.25 – 0.30 mm and the weight of 300g. The fluidised layer has advantageous conditions to conduct the combustion of solid, liquid and gaseous fuels[2 – 12] as the following conditions for the bed's properties have been met: thorough mixing of the substrates which participate in reactions, stable

Table 1. The composition of Tetra Pak packages

Material / Source	Paper		Polyethylene (PE)	Aluminium
	cellulose	incombustibles		
	[% d.b.]	[% d.b.]	[% d.b.]	[% d.b.]
Data provided by the producer and professional literature [1][15]	75		20	5
Chemical analysis	72.31	2.95	20	4.74

temperature thanks to the fluidised layer's thermal inertness and the prospect of granulating the waste on a certain level of burning by grinding with the bed's grains. The bed's temperature control system of the reactor used to conduct the research enables studying and marking of the optimum process parameters. Aluminium containing Tetra Pak and Combibloc packages were prepared for the incineration by being cut into rectangular 3 – 6 mm objects. When cut into such objects, it was possible to feed them into the furnace using a revolving-plate feeder. The furnace was preheated with propane and the average stream of waste fed into it was ca 0.25 g/s.

The usefulness of a given material for thermal energy production is determined, with many factors involved, but the most important ones are: the heating value, the content of the flammable and inflammable parts, the humidity and the amount of pollution produced by burning. The heating value was calculated by using Dulong's, Mendeleiew's and Mahler's formulas[13]. Table 2 demonstrates a comparison of the calculated values and the data found in professional literature regarding Tetra Pak packages.

Incinerating multilayer packages means using renewable fuel (cellulose). Therefore, it means lowering the carbon dioxide emission by the amount of carbon dioxide produced from burning the equivalent amount of coal. The results of calculating the emission's amount when generating 1MJ of energy ("green" emission of carbon dioxide) are shown in Table 3.

While burning the material, the combustion gases' composition was analyzed ca 200mm above the exhausts' bed. Figures 2 & 3 show the gases' composition of O_2, CO, CO_2, NO_x, SO_2 and VOCs from two experiments: with and without secondary air. In the second one (Figure 3) the emission of nitrogen oxides and sulphur dioxide was below the emission standards[14] for waste combustion installation.

The dust rising from the furnace was collected in the ash trap and in the cyclone. It was observed that the dust from the ash trap is composed of two structural constituents, which can be separated through spreading. The ISP-MS analysis was applied to both fractions from the ash pan, the dust from the cyclone, the bed and the samples of multilayer packages (Tables 4 & 6). Its results allowed a calculation of the upper limit of heavy metals' emission and their compounds and their influence on the incinerating plant's construction when assuming that all the emitted gases are not purified.

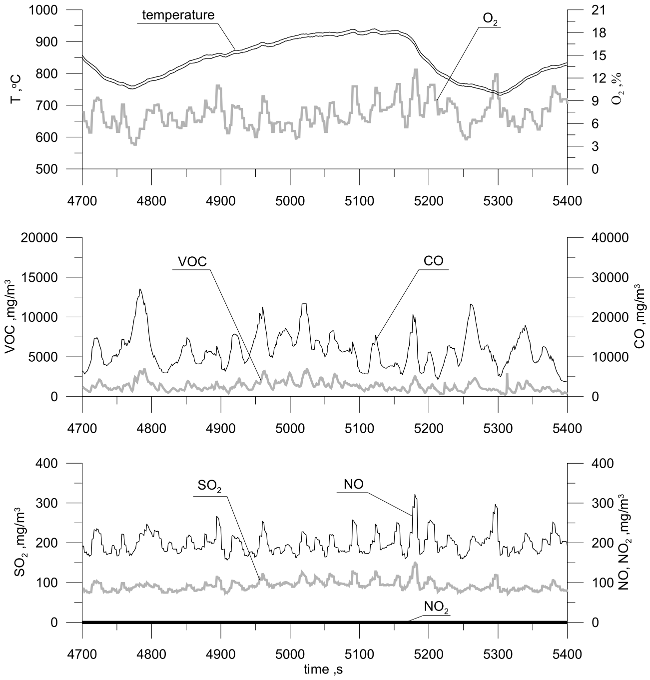

Figure 2. Flue gases composition during the multilayer packages combustion without secondary air. Various bed temperature (730 °C - 930 °C) and O_2 (3% – 13%). Concentrations standardised at 11%O_2 in flue gases

Table 2. The heating Value of Tetra Pak packages

	Upper heating value [MJ/kg]		Lower heating value [MJ/kg]	
	cellulose	polyethylene	cellulose	polyethylene
Data from professional literature	18.61[1] [16][17]	47.74 [18]	17.25[2]	44.6 [18]
	17.4 [19]	46.2 [20]	16.04[2]	43.06[2]
	18.36[2]	46.14[2]	17.0 [15]	43 [15]
Values used for further calculations	18.4	47.0	17.0	43.8
	Tetra Pak packaging		Tetra Pak packaging	
Values calculated using heating value of cellulose and LDPE	22.7		21.1	
Data from professional literature	22.4 [15]		20.8[2]	
Value calculated using the Dulong formula	20.2[2]		18.6	
Value calculated using the Meneleiev formula	23.6[2]		22.0	
Value calculated using the Mahler formula	22.9		21.3[2]	
Values used for further calculations	22.4		20.8	

[1] The value was calculated after converting [BTU/lb] to [kJ/kg]

[2] The value calculated using the formula $W_d = W_g - r*9H$, where: H– mass fraction of hydrogen in the material, r – enthalpy of water evaporation at 298 K, r = 2442.4 kJ/kg

Table 3. Carbon dioxide emission

Carrier	Heating value	Mass fraction of coal in 1 [Mg] of fuel	„Green" CO_2 emission	Total CO_2 emission	„Green" emission / total emission
	[MJ/kg]	[kg]	[kg/MJ]	[kg/MJ]	[%]
Coal	30.3 [21]	805 [21]	0.0	97.4	0.0
Cellulose	17.0	444	95.8	95.8	100.0
Polyethylene	43.8	857	0.0	71.7	0.0
Tetra Pak	20.8	493	56.6	86.8	65.2

Table 4. The composition of fuel and solid combustion products – heavy metals

	Fuel – TETRA PAK	Total – bed	Trick fraction – ash pan	Fine fraction – ash pan	Total – cyclone
Constituent	[mg/kg $_{d.b.}$]	[mg/kg $_{d.b.}$]	[mg/kg $_{d.b.}$]	[mg/kg $_{d.b.}$]	[mg/kg $_{d.b.}$]
Cd	0.069	0.019	0.336	0.168	0.784
Tl	0.022	0.012	0.132	0.113	0.155
Amount I	0.091	0.031	0.469	0.281	0.939
Hg	0.062	0.033	0.058	0.029	0.092
Amount II	0.062	0.033	0.058	0.029	0.092
Cr	3.443	5.081	10.311	16.844	28.467
Pb	3.061	1.778	18.668	14.061	41.067
Co	0.230	0.216	1.671	1.670	2.287
Ni	2.423	1.806	16.388	13.915	21.467
Mn	16.835	9.315	113.199	117.178	195.720
V	3.699	2.823	23.660	32.224	18.293
Cu	13.136	20.981	89.756	48.629	64.587
As	0.140	0.100	0.304	0.488	0.793
Sb	0.045	0.013	0.027	0.041	0.007
Amount III	43.012	42.113	273.985	245.051	372.687

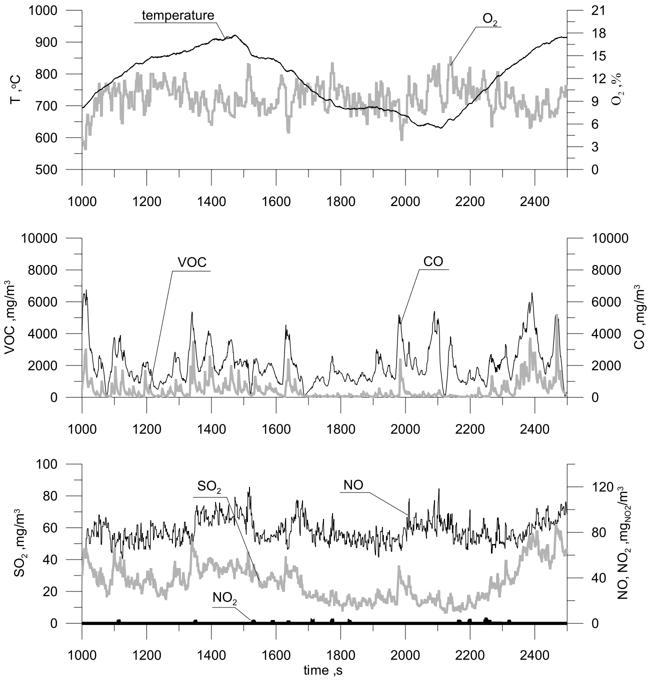

Figure 3. Flue gases composition during multilayer packages combustion with secondary air. Various bed temperature (700 °C – 900 °C) and O_2 (3% – 15%). Concentrations standardised at 11%O_2 in flue gas

Table 5. Maximum emission of heavy metals in flue gases

Constituent	Concentration in flue gases		Emission standards [14]
	No Al oxidation	With Al oxidation	
	$[mg/m_u^3]$	$[mg/m_u^3]$	$[mg/m_u^3]$
Cd	0.007	0.006	
Tl	0.002	0.002	
Amount I	0.009	0.009	0.05
Hg	0.006	0.006	
Amount II	0.006	0.006	0.05
Cr	0.329	0.322	
Pb	0.292	0.286	
Co	0.022	0.021	
Ni	0.231	0.226	
Mn	1.608	1.573	
V	0.353	0.346	
Cu	1.255	1.228	
As	0.013	0.013	
Sb	0.004	0.004	
Amount III	4.108	4.020	0.5

The calculation of the amount of dry exhausts produced by the burning of Tetra Pak packages was done under the assumption that the only flammable components are cellulose and polyethylene. In this case the volume of dry flue gases equals $V_{ss}=10.47\ m_u^3{}_{11\%O2}/kg_{s.m.}$. Assuming that all the aluminium in the packages becomes oxidized then $V_{ss}=10.70\ m_u^3{}_{11\%O2}/kg_{s.m.}$. The maximum emission results are shown in Table 5.

The calculations prove that the content of cadmium, thallium and mercury in the flue gases is lower than the emission standards[14], therefore it is possible to omit them during the analysis of the exhausts' composition. On the other hand, considering that "Amount III" is composed mostly of non-volatile substances so most of them turn to dust (Table 4), which implies using a dust filtering system with a total efficiency of 90% (that is also necessary to recover aluminium), which is needed to meet the emission standards. In addition, it has been established in which form aluminium leaves the fluidised bed reactor by chemically analyzing and calculating the mass balance of the main oxide constituents. It was determined that the fine fraction consists of very large amounts of metallic aluminium that constituted almost half of the entire fraction. The amount was lower in the thick fraction and in the ash deposited in the cyclone but still higher than the amount of aluminium oxide. Figure 4 shows the solid combustion products from the combustion with secondary air.

CONCLUSION

The research shows a possibility of utilizing multilayer packages as fuel for fluidised bed furnaces, while the combustion of such materials causes a relatively small emission of gaseous pollution. The knowledge of the chemical composition of these packages makes it possible to use them as alternative fuel, to which biomass emission standards can be applied. Their combustion will contribute to decreasing carbon dioxide concentration in the atmosphere. Using pneumatic conveying enables the separation of the inflammable parts of the fuel, including the ones that contain aluminium. A significant amount of aluminium is deposited in its elementary form. Thus, heat recovery

Table 6. The composition of fuel and solid combustion products – oxides as the main ingredients

Constituent	Fuel – TETRA PAK	Total – bed	Trick fraction – ash pan	Fine fraction – ash pan	Total – cyclone
	[mg/kg $_{d.b.}$]	[mg/kg $_{d.b.}$]	[mg/kg $_{d.b.}$]	[mg/kg $_{d.b.}$]	[mg/kg $_{d.b.}$]
Na	1048.348	988.844	2402.908	2289.373	7733.600
Na_2O, %	0.14%	0.13%	0.32%	0.31%	1.04%
K	274.203	1159.140	20751.399	3976.743	26497.333
K_2O, %	0.03%	0.14%	2.50%	0.48%	3.19%
Mg	193.855	143.011	880.198	1432.506	2874.667
MgO, %	0.03%	0.02%	0.15%	0.24%	0.48%
Ca	4754.551	3507.527	36792.491	216194.191	258346.667
CaO, %	0.67%	0.49%	5.15%	30.27%	36.17%
Al	47405.217	27990.591	405911.263	487901.660	298106.667
Al, %	4.74%		28.97%	40.39%	14.35%
Al_2O_3, %		5.29%	21.94%	15.87%	29.21%
P	1.275	16.935	375.522	1.465	707.467
SiO_2, %	1.81%	88.44%	40.96%	12.45%	15.56%

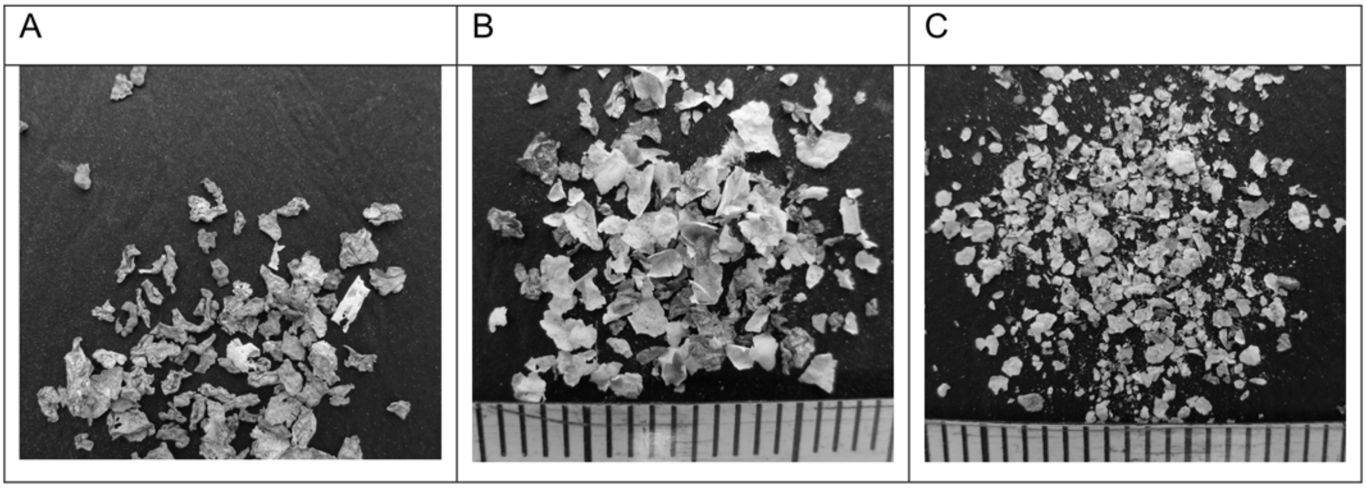

Figure 4. Solid combustion products (with scale in millimetres): a – material from the bed, fraction > 0.5 mm, b – ash from the ash trap, c – ash from the cyclone

can be accompanied by resource recycling of the aluminium contained in the packages. It was also proved that other constituents of dust are not toxic and their emission can be easily decreased to meet the emission standards of heavy metals in waste utilization processes.

LITERATURE CITED

1. Jönsson, D. (2007). Sustainable by Nature, Environmental and Social Report. Retrieved July 10, 2008, from http://www.tetrapak.com/Document%20Bank/env_and_soc_rep.pdf

2. Avedesian, M. M. & Davidson J. F. (1973). Combustion of carbon particles in a fluidised bed. *Trans. I. Chem. E.* 51a, 121 – 131.

3. Baron, J., Bulewicz E. M., Kandefer S., Pilawska M. & Żukowski W. (2006). A simple physicochemical view of bubbling FBC. In Revelling in Reference: 19th International Conference on Fluidized Bed Combustion, 21 – 24 May 2006 (Paper 43C). Vienna, Austria.

4. Baron, J., Bulewicz E. M., Żukowski W., Kandefer S. & Pilawska M. (2002). Combustion of hydrocarbon fuels in a bubbling fluidized bed. *Combust. Flame* 128(4), 410 – 421. DOI: 10.1016/S0010-2180(01)00359-5.

5. Baron, J., Bulewicz E. M., Kandefer S., Pilawska M., Żukowski W. & Hayhurst A. N. (2006). The combustion of polymer pellets in a bubbling fluidised bed. *Fuel* 85(17 – 18), 2494 – 2508. DOI: 10.1016/j.fuel.2006.05.004.

6. Bulewicz, E.M., Żukowski W., Kandefer S. & Pilawska M. (2003). Flame flashes when bubbles explode during the combustion of gaseous mixtures in a bubbling fluidized bed. *Combust. Flame* 132(3), 319 – 327. DOI: 10.1016/S0010-2180(02)00466-2.

7. Dennis, J.S., Hayhurst A.N. & Mackley I.G. (1982). The ignition and combustion of propane/air mixtures in a fluidised bed. In Revelling in Reference: 19th Symposium (International) on Combustion (Vol. 19(1), 1205 – 1212). Pittsburgh: The Combustion Institute. DOI: 10.1016/S0082-0784(82)80297-X.

8. Hesketh, R.P. & Davidson J.F. (1991). Combustion of methane and propane in an incipiently fluidized bed. *Combust. Flame* 85(3 – 4), 449 – 467. DOI: 10.1016/0010-2180(91)90147-4.

9. Pilawska, M., Baron J. & Żukowski W. (2005). Combustion of Aromatics and Esters in an Atmospheric Bubbling Fluidized Bed Combustor, in Comparison with that of Natural Gas. *Clean Air* 6(2), 113 – 123. DOI: 10.1615/InterJEnerCleanEnv.v6.i2.20.

10. Żukowski, W. (2003). A simple model for explosive combustion of premixed natural gas with air in a bubbling fluidized bed of inert sand. *Combust. Flame* 134(4), 399 – 409. DOI: 10.1016/S0010-2180(03)00139-1.

11. Żukowski W. (2004). *Combustion of Gaseous Fuels in a Fluidised Bed of Inert Particles* (in Polish). Cracow, Poland: Cracow University of Technology

12. Żukowski W. (2005). Methane and ethane Combustion in an Inert Fluidized Bed. In Revelling in Reference: 18th

International Conference on Fluidized Bed Combustion, 22 – 25 May, 2005 (paper FBC2005-78100). Toronto: ASME.

13. Żygadło M. (1998). *Gospodarka odpadami komunalnymi*. (Municipal waste management – in Polish), Kielce: Wyd. Politechniki Świętokrzyskiej.

14. Rozporządzenie Ministra Środowiska z dnia 20 grudnia 2005 r. w sprawie standardów emisyjnych z instalacji (Dz.U. 2005 nr 260 poz. 2181).

15. Wandrasz J.W. & Wandrasz A. J. (2006). Paliwa formowane. *Biopaliwa i paliwa z odpadów w procesach termicznych*. (Formed fuels. Biofuels and fuels from waste in thermal processes – in Polish), Warszawa: Wyd. "Seidel-Przywecki" Sp. z o.o., first edition.

16. Baker, A.J. (1982). Wood fuel properties and fuel products from woods. In Revelling in Reference: Fuelwood Management and Utilization Seminar, 9 – 11 November 1982 (pp. 14 – 25). East Lansing, MI: Michigan State University. Retrieved July 10, 2008, from http://www.fpl.fs.fed.us/documnts/pdf1983/baker83a.pdf

17. White, R.H. (1987). Effect of lignin content and extractives on the higher heating value of wood. *Wood and Fiber Science* 19(4), 446 – 452. Retrieved July 10, 2008, from http://www.fpl.fs.fed.us/documnts/pdf1987/white87a.pdf

18. Richard, N.W., Stacey M.H. & Richard E.L. (2000). Heats of combustion of high temperature polymers. *Fire and Materials* 24(5), 245 – 252. DOI: 10.1002/1099-1018(200009/10)24:5<245::AID-FAM744>3.0.CO;2-7.

19. The Environment and You, (©2007 Chill Entertainment). Retrieved July 10, 2008, from http://environmentandyou.org/energy.php

20. Babrauskas, V. (1992). Related Quantities. Part A. Heat of Combustion and Potential Heat. In V. Babrauskas & S. J. Grayson (Eds.), *Heat Release in Fires* (pp. 207 – 223). New York: Elsevier Applied Science. Retrieved July 10, 2008, from http://www.fire.nist.gov/bfrlpubs/fire92/PDF/f92030.pdf

21. Szargut, J. (1998). *Termodynamika*. (Thermodynamics – in Polish), Warszawa: Wyd. Naukowe PWN, VI edition.