PhD Thesis Contents

The existence of high poultry meat production, followed by a large quantity of waste that creates significant problems in handling, storage, and environmental impact, has led to the search for innovative solutions for managing these wastes in compliance with EU directives, with the objective of achieving a "circular economy".

A circular economy requires the disposal of productive waste, which is recommended to become "raw material" for other processes. From an energetic perspective, this plays an important role, and it should not be confused with the general principle of energy production from renewable resources, which includes the use of wind power, solar radiation, and the potential and kinetic energy of water.

From these considerations, it follows the need to pay special attention to the use of agricultural waste, industrial and household waste in energy production, with the effect of producing totally environmentally neutral waste.

Circular energy will also lead to rural development, with agricultural farms developing through intrinsic energy production, minimizing reliance on centralized electricity production.

As a consequence of the intensifying global energy crisis, society must support the concept of circular energy, ranging from financial assistance to aligning legislation with market demand and environmental protection. The current development plans in the EU respond to these aspirations.

The doctoral thesis entitled *"The Integrated Energetic and Ecologic Valorization of Waste from the Poultry Sector"* addresses the topic of co-combustion of raw poultry waste with woody biomass and is a consequence of the high poultry production in Romania. The problems caused by energy costs for maintaining poultry production complexes, the generation of agro-zootechnical waste, and the costs associated with environmental fees find an innovative and efficient solution within the thesis.

The subject of this thesis responds to the requirements of the current development of society, by using renewable energy, in parallel with the reduction of pollution.

In the framework of the thesis, the achievement of two objectives is considered. The first aims at reducing pollution by reducing the amount of poultry waste stored at the source, in the poultry complexes, and the second at the production of internal thermal energy that can be used to heat the respective farms. Obtaining energy from waste at source, as proposed by the present thesis research, can be a viable technological solution for energy recovery of poultry waste in a thermal power plant co-combustion of poultry waste with solid biomass.

The content of the doctoral thesis was structured in 6 chapters, followed by the seventh one referring to general conclusions, contributions and research perspectives.

Chapter 1, *"Biomass, an important element in a circular economy"*, begins with the presentation of the concept of biomass, which includes both woody biomass and bird waste, as well as their role in a circular economy. It starts from the concept that a circular economy involves the elimination of waste with productive potential, which will become a source for other technological processes in the cascade. As a result, after combustion, poultry waste becomes a fertilizer through the resulting ash, enriched in phosphorus and calcium.

The energy obtained through the co-combustion of woody biomass with poultry waste represents a renewable energy, falling within the current legislation for the reduction of CO_2 emissions. Thus, within the Paris Agreement of 2015, bird droppings are included in the category of renewable sources of bioenergy.

In the chapter, the main technologies of using biomass for energy generation were also analyzed, namely: thermo-chemical processes of which direct combustion is also a part, bio-chemical processes and physico-chemical processes. The chapter concludes with a synthetic analysis of the pollutant emissions related to the combustion technology of poultry waste.

Chapter 2, *"Energy problems specific to intensive poultry production"*, presents in the first part the particularities of intensive poultry breeding in large industrial complexes. The notion of the period of growth of birds with all the necessary climate conditions (temperature, ventilation, humidity) is specified.

The specific elements of this activity were also presented, such as the number of growing birds in relation to the surface unit, the amounts of resulting droppings and the particularities of ventilation in relation to the outside temperature, and to the degree of maturity of the brood. Table 1 summarizes the microclimate recommendations for poultry houses.

Table 1. General microclimate recommendations for poultry houses

Category	Temperature, ℃			Humidity, %	Air speed, m/s	
	Min.	Max.	Optimum		Min.	Max.
Production birds	12	24	13 - 18	65	0,3	1,5
Breeding birds	14	24	16 - 18	65	0,3	1,5
Youth production						
Week I	33	35,5	-	60	0,15	0,5
Week II	30	32	-	60	0,15	0,5
Week III	26	29	-	60	0,15	0,5
Week IV	21	25	-	60	0,15	0,5
Week V	18	20	-	60	0,15	0,5
Week VI - VII	-	-	17	60	0,15	0,5
Week VIII - IX	-	-	16	60	0,15	0,5
Week X - XI	-	-	15	60	0,15	0,5
Week XII - XIII	-	-	14	60	0,15	0,5
Week XIV - XV	-	-	13	60	0,15	0,5
Week XVI - XVII	-	-	12	60	0,15	0,5

Clarifications are made regarding the difference between summer and winter when achieving the temperatures imposed in the halls, depending on the period of growth of the birds.

The data presented in this chapter constituted the fundamental basis of the air conditioning calculations of chicken rearing halls with the help of wood biomass co-combustion with poultry waste.

Chapter 3, *"General elements specific to the heating of poultry sheds"*, presents a detailed analysis, based on the specialized literature, of this essential problem in the development of the thesis topic.

The first general problem addressed in this chapter investigated the essential aspects, specific to the heating of poultry production halls. The references were made indicatively for a temperate-continental climate such as that of Romania. Moreover, the function of ventilation was also analyzed, in correlation with the temperature of the environment and the period of growth and even the degree of stress of the birds in a production hall. For the heating function, the constructive particularities of the poultry houses were introduced, taking into account the body heat of the birds.

In this chapter, multiple data and requirements necessary for the construction and operation of a poultry complex were synthesized and original contributions were made by creating a synthetic calculation model for the heating-ventilation system for a hall of special construction intended for raising birds from Giurgiu county, Buturugeni, Figure 1.

Fig. 1. Picture of the halls of the Buturugeni Farm, Giurgiu county

The presented calculation model includes all the thermal flows that affect the space of a poultry rearing hall, offering through this application on a real case an analysis that will be the basis of the validation of the calculation model for heating - ventilation through the combustion of poultry manure with solid biomass. The numerical application made by referring to an imposed density of the number of birds in the house (18 birds/m^2), as can be seen in Figure 2, growth cycle of 56 days, with a body heat of 0.12 kWh/day bird, demonstrated the correctness of energy consumption for heating and ventilation of halls. Interpreted and processed data sets were created, which will be the basis of the validity criterion of the original model proposed for air conditioning the halls through the co-combustion of woody biomass with poultry manure.

Fig. 2. Images hall 1 – Buturugeni Farm, Giurgiu county

The chapter ends with an analysis of data from the specialized literature regarding energy consumption specific to intensive poultry breeding spaces. The study includes an analysis for a hall with the size of 1500 m^2. Following this analysis, the size of the hall module space of 1000 m3 used in the original air conditioning study model with the heat obtained through the co-combustion of woody biomass with avian waste was adopted.

Chapter 4, *"The energetic characteristics of poultry manure and thermal neutralization technologies"*, records the energetic characteristics of avian waste as determined experimentally in the laboratory at the Department of Thermotechnics, Engines, Thermal and Refrigerating Equipment, POLITEHNICA University of Bucharest and which they included:

- elemental analysis, which represents the most complete and complex analysis for an energetic fuel;
- technical analysis, which defines the content of volatiles, the main element for the ignition phase;
- lower calorific value.

The low energy quality of poultry manure was highlighted, especially due to their high moisture content. The samples taken for the laboratory analysis of poultry manure were considered at the state at the time of evacuation from the poultry rearing halls, resulting in a very high humidity in the range of 36.1 - 40.3% for pure manure, and 36.0 - 40 .0% for manure mixed with biomass from the bed placed in the halls. The biomass bed in the avian waste sample was determined to have a mass participation of 10%.

The lower calorific value was very low, 3800 kJ/kg to 6000 kJ/kg. It was also compared with the values from the specialized literature for other categories of solid fuels.

Starting from these characteristics for avian waste, the performances that can be obtained in the conversion (thermal processing), through the technologies of gasification, pyrolysis and direct combustion, were analyzed.

Regarding gasification, a case study was presented regarding the gasification of pellets of biomass mixture with poultry manure, carried out in Poland, for a pilot gasogen with a fixed bed, with downward flow, for a flow rate of 5kg/h.

Results were obtained for a mixture of partially dried wood and poultry manure, so the calorific value was relatively high up to 10966 kJ/kg. The study demonstrated the achievement of lower calorific value gasogen gas, between 2000 kJ/m_N^3 for single poultry manure and 4000 kJ/m_N^3 for a 75% wood mixture, but with high reported costs.

The use of primary fuel in the form of pellets led to an increase in the calorific value of gasogen gas by about 20-25% (Figure 3).

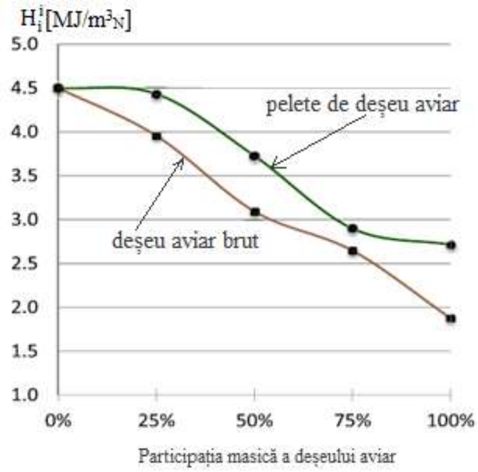
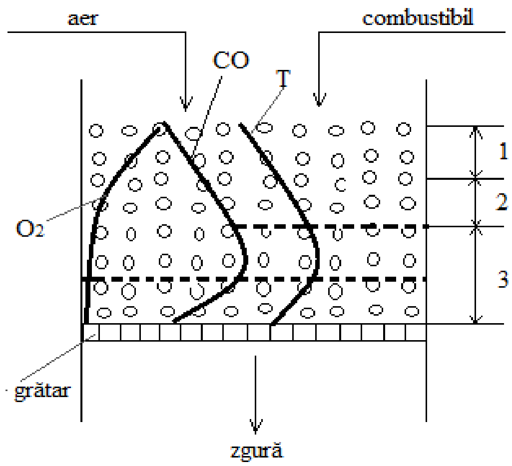


Fig. 3. Calorific value of gasogen gas

The pyrolysis of raw poultry manure was presented through the research achievements of the Politehnica University of Bucharest, Department of Thermotechnics, which highlighted an efficient process from an energetic point of view, the coke created being "clean" and with a potential energy higher than the global energy consumption for pyrolysis. However, the use of pyrolysis has not yet solved the technical problems related to the supply of the plant, the exhaust of the final combustible product and the internal heating required for the process.

Next, the fixed bed direct combustion technology was theoretically and experimentally investigated. In accordance with the data from the specialized literature, the particularities of this combustion technology are presented, highlighting the influence of fuel size, porosity and air flow along the fuel layer. Figure 4 shows the variation of combustion products and temperature for equicurrent combustion, and Figure 5 for countercurrent combustion.



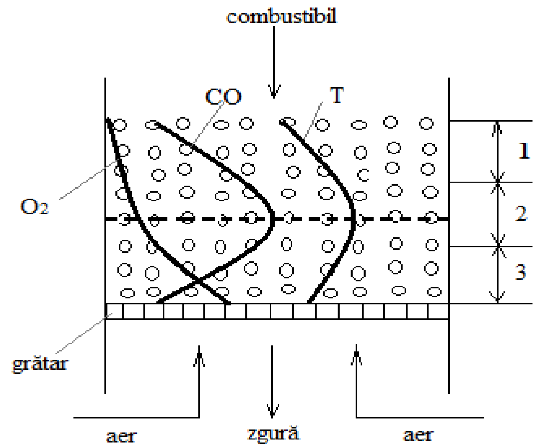


Fig. 4. Schematic of the layer combustion process, combustion in equicurrent;

Fig. 5. Schematic of the layer combustion process, countercurrent combustion

1 – the volume subjected to heating;
2 – the volume subject to devolatilization;
3 – the volume in the perimeter of the effective combustion.

To reduce the carbon monoxide emission, which is high for any biomass, including by applying this combustion technology, the importance of the secondary air blown in the final part of the hearth was highlighted.

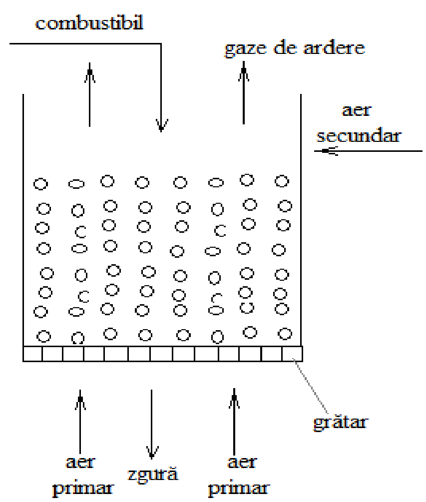


Fig. 6. Secondary air injection scheme to reduce carbon monoxide emissions

The problem of direct combustion was addressed in detail, because it constitutes the application developed for the fuel consisting of the mixture of solid biomass with raw bird droppings. A major contribution was given to the influence of the fuel density in the fixed bed on the global development of the combustion process.

According to laboratory determinations, the lower calorific value of 3800-6000 kJ/kg is below the limit of use for energy purposes. As a result, the co-combustion solution with woody biomass was imposed.

Chapter 5, *"Fixed Bed Biomass Poultry Waste Co-combustion Research"*, presents and evaluates the experimental results obtained on fixed bed combustion of poultry manure. These are the basis for the realization of an original conceptual model for the co-combustion of poultry manure with woody biomass. The realized conceptual model includes low-density fixed-bed combustion to control the combustion of poultry manure fed in the upper part of the bed, with the limitation of CO emission. The conceptual synthesis of the proposed combustion model is presented in Figure 7, which highlights the connection between the lower calorific value, the density of the fuel layer and the burning speed *u* in *m/s*.

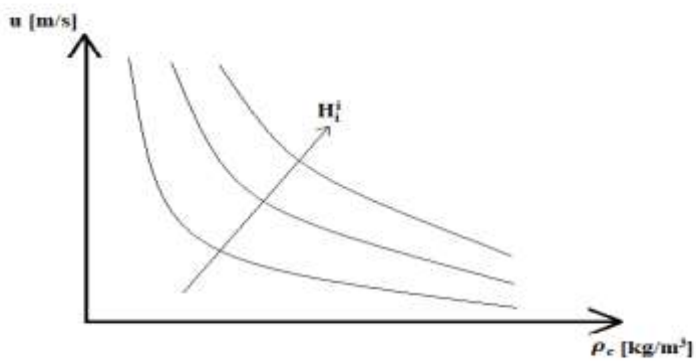


Fig. 7. The law of the variation of the burning rate in a fixed bed of fuel

For the experiments, a pilot boiler of 55 kW was used, from the POLITEHNICA University of Bucharest, Department of Thermotechnics, Engines, Thermal and Refrigerating Equipment, a boiler intended for the production of residential heat, which was equipped with all the necessary measurement and control equipment, Figure 8. Flue gas analysis, including pollutant emissions, was determined with a MAXLYZER NG analyzer mounted at the boiler outlet. For burning solid fuels, the boiler is equipped with a fixed grate with cast iron bars. The firebox has a useful volume of 0.25 m^3. For the heat balance, the flow of heated water, as well as its temperature at the inlet and outlet, are continuously measured.

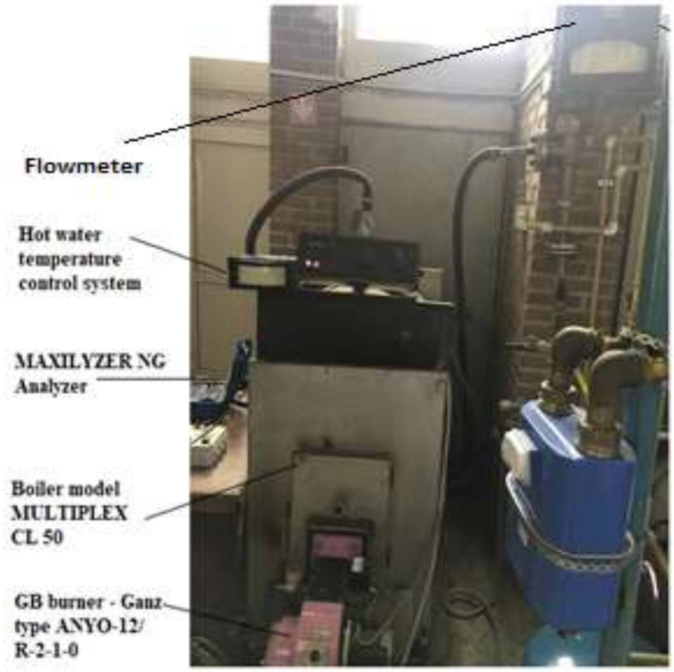


Fig. 8. Pilot plant, 55 kW boiler from the Thermotechnical Laboratory

Table 2 presented the energy characteristics of the solid biomass used in the form of elemental analysis and calorific value.

Table 2. Energy characteristics of the types of solid biomass used

Biomass	**Ci**	**Hi**	**Oi**	**Ni**	W_t^i	**Ai**	H_i^i
	%	**%**	**%**	**%**	**%**	**%**	**MJ/kg**
Dry wood	47,0	5,0	34,1	0,5	10,1	3,3	17,17
Wood with medium moisture	32,9	4,6	28,6	0,7	30	3,2	12,01
Branches	36,7	5,2	30,8	0,6	25,2	1,5	13,80
Ropes of vines	40÷43	3,7÷4,9	35÷42	0,6÷2,5	10÷26	2,5÷4,5	14,7÷15,8

Poultry manure had a mass contribution of 13%, for the first experiment and 30% in the second experiment, compared to woody or agricultural biomass. The combustion process was monitored sequentially over time, as shown in Figure 9 and Figure 11.

Pollutant emissions shown in Tables 3 and 4 were within the permitted limits. No NH_3 emissions were recorded, as a result of the combustion of this gaseous component in the ember layer.

Figures 10 and 12 respectively show the evolution of the parameters measured with the MAXILYZER NG flue gas analyzer during the fixed bed co-combustion process of the fuel mixture for experiment 1 and experiment 2, respectively.

EXPERIMENT 1

Table 3. Experimental parameters measured by the MAXILYZER NG flue gas analyzer

Parameters / STEP	Hour	O_2 [%]	CO_{+} [%]	CO_2 [%]	T_{gaze} [^{O}C]	T_{aer} [^{O}C]	Dif. t [^{O}C]	NO_X [ppm]	SO_x [ppm]	λ	η %
I	11:06:29	9,6	0,48	11,1	387	22,9	363,1	81	0	1,84	77,9
	11:07:41	9,8	0,541	10,9	386	21,6	363,4	75	0	1,88	77,6
II	11:11:34	11,5	0,188	9,2	307	22,3	283,7	72	0	2,21	79,8
	11:14:16	13	0,136	7,8	279	22,3	256,7	61	0	2,63	78,7
	11:15:36	13,3	0,159	7,5	275	22,3	252,7	56	0	2,73	78,3
III	11:23:52	10,1	0,363	10,6	331	24,1	305,9	67	0	1,93	80,7
	11:24:15	9,2	0,632	11,5	365	23,9	341,1	74	0	1,78	79
	11:24:27	8,8	0,713	11,9	364	24,2	339,8	81	0	1,72	80,5
	11:25:12	9,8	0,403	10,9	383	24,1	357,9	100	0	1,88	77,9
	11:27:29	13,7	0,179	7,1	300	24,5	275,5	82	0	2,88	75,2

Fig. 9. Images of the combustion process inside the hearth of the 55 kW pilot boiler at different times of experiment 1

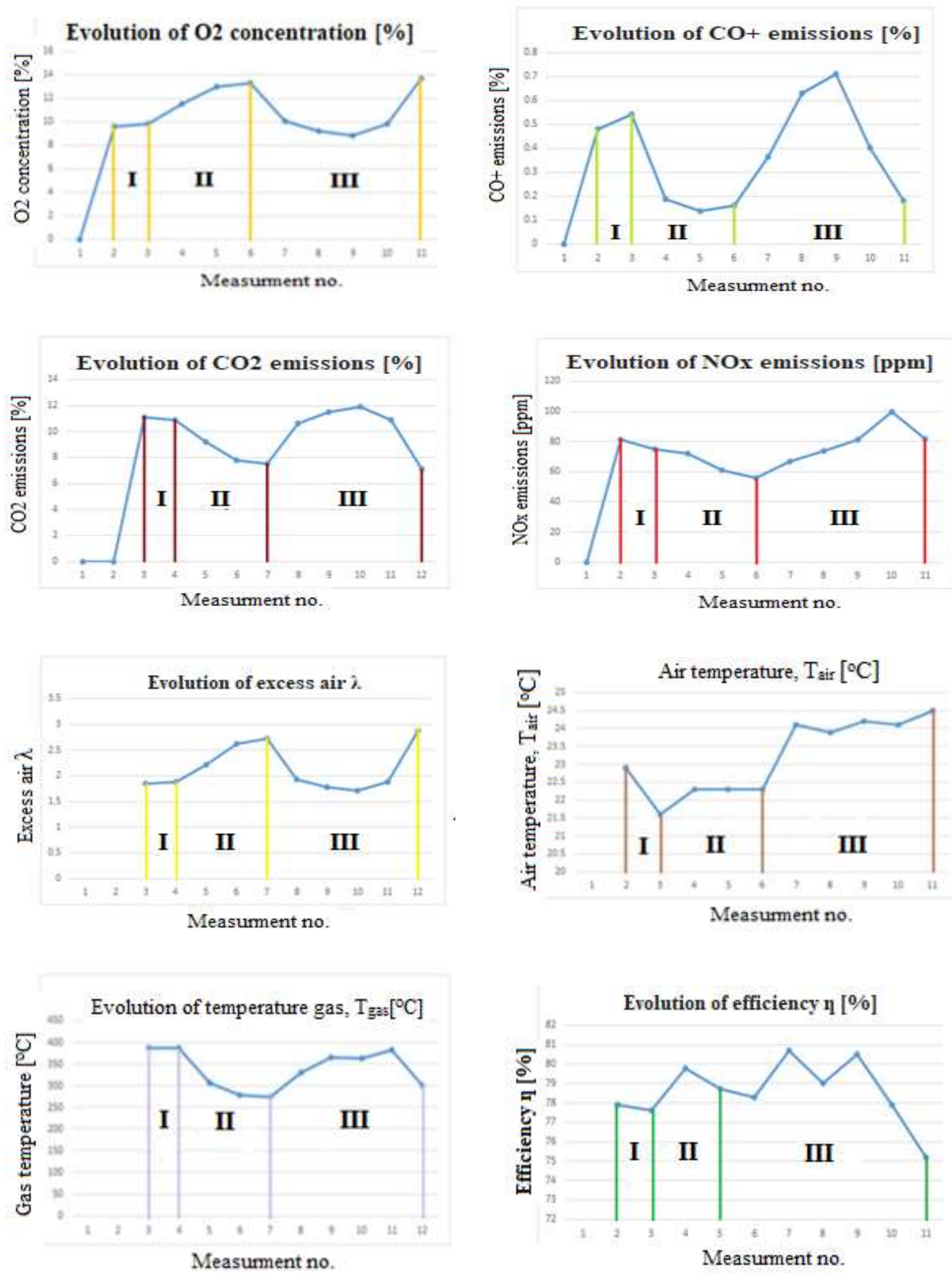


Fig. 10. The evolution of the parameters measured with the MAXILYZER NG flue gas analyzer during the fixed bed co-combustion process of the fuel mixture – experiment 1

EXPERIMENT 2

Tabel 4. Experimental parameters measured by the MAXILYZER NG flue gas analyzer

Parameters / Nr. crt.	Hour	O_2 [%]	CO_+ [%]	CO_2 [%]	T_{gaze} [^{O}C]	η [%]	NO [ppm]	NO_X [ppm]	SO_x [ppm]	λ
1.	11:48:11	8,9	0,707	11,7	443	75,5	119	119	-	1,75
2.	11:50:16	8,7	0,716	12,0	505	72,6	166	169	-	1,71
3.	11:52:24	7,4	1,185	13,2	541	73,0	122	121	0	1,54
4.	11:53:07	7,3	1,140	13,3	553	72,5	131	131	0	1,53
5.	11:55:15	8,6	1,070	12,1	522	71,8	110	110	0	1,69
6.	11:56:36	9,8	0,739	10,9	501	70,5	116	116	0	1,88
7.	11:58:19	15,4	0,285	4,8	427	53,4	106	106	0	4,20
8.	11:58:52	12,6	0,286	11,9	448	66,4	141	137	0	2,50
9.	12:25:28	17,5	0,273	3,4	169	74,3	22	22	0	6,00

Fig. 11. Images of the combustion process inside the hearth of the 55 kW pilot boiler at different times of experiment 2

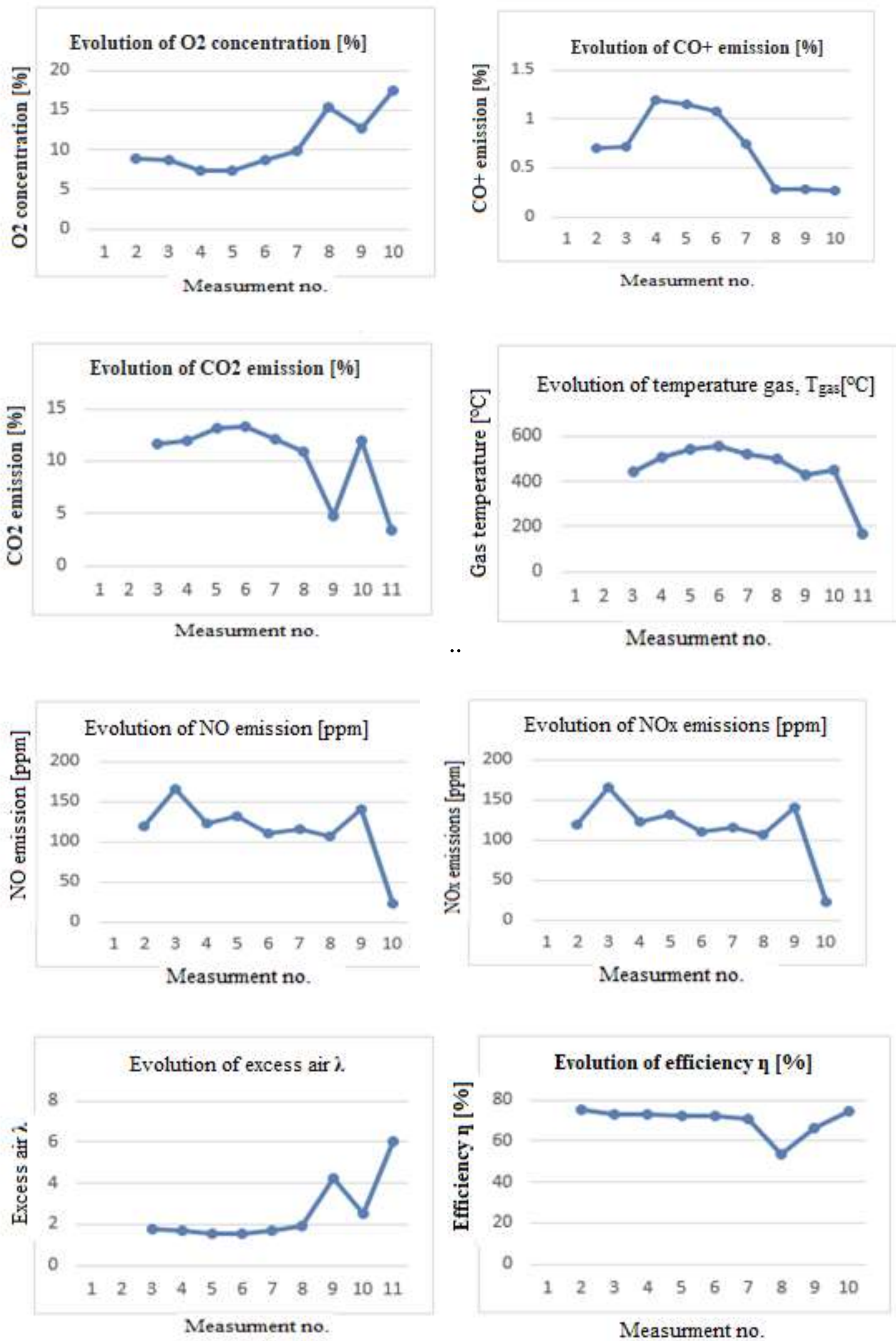


Fig. 12. The evolution of the parameters measured with the MAXILYZER NG flue gas analyzer during the fixed bed co-combustion process of the fuel mixture – experiment 2

The variation of the boiler efficiency with the temperature of the flue gas discharged to the chimney for experimental 1 is presented in Figure 13, respectively for experimental 2 in Figure 14.

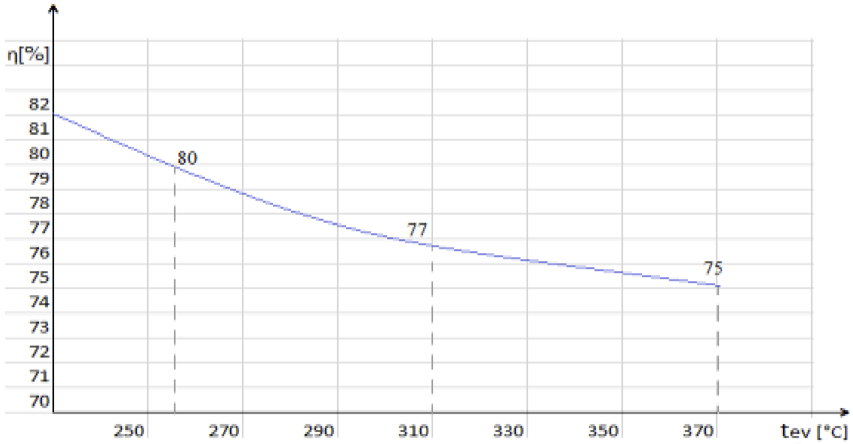


Fig. 13. The variation of the efficiency of the energy plant with the temperature of the combustion gases at the exhaust – Experiment 1

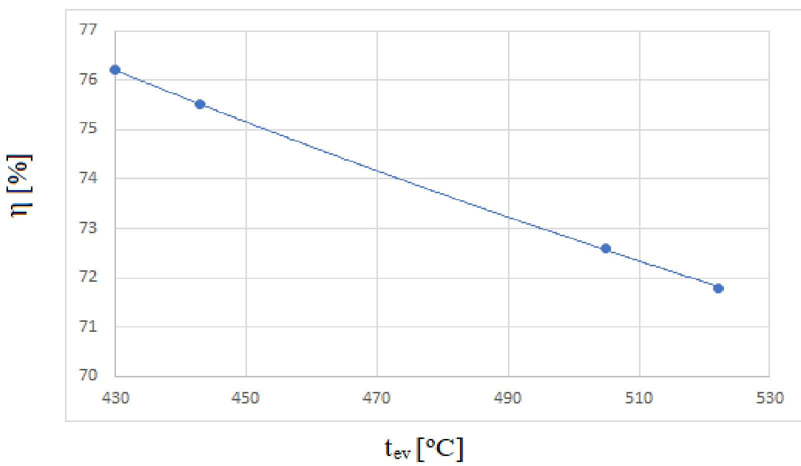


Fig. 14. The variation of the efficiency of the energy plant with the temperature of the combustion gases at the exhaust – Experiment 2

The second combustion experiment for which the increase in the amount of poultry waste was up to 30%, reconfirmed the positive conclusion from the first experiment. The data derived from this experimentation led to the conclusion that the dosage limit of 30% of poultry manure to biomass (expressed gravimetrically) has reached the level from which the performances in their totality are decreasing.

As a general conclusion drawn after this series of experiments, it can be mentioned that this technology of co-combustion of wet bird waste together with biomass, for the production of thermal energy, represents a positive solution, capable of being applied industrially at the level of a farm poultry.

Chapter 6, *"Heating a Poultry Complex Using Manure at the Source"*, considered the possibility of using this manure in co-combustion with solid biomass to produce thermal energy at the air conditioning level of a poultry complex. For this purpose, an original calculation model was created for a poultry activity module of 1000 m^3. The obtained results can be extended to any industrial level for a poultry complex.

The thermal calculations were based on experimentally determined co-combustion results, included in the air conditioning mechanism of the halls accepted by the Ministry of Agriculture. According to Romanian legislation, the thermal power for heating a hall must be 40 W/m^2. For a 20% participation in gravimetric percentages of poultry manure, a calorific value of 12500 kJ/kg was obtained for the fuel mixture, and an efficiency of 88% was considered for the boiler.

The calculated method included periodic cycles of eight weeks each, with the climate conditions imposed by the maturity of the chickens presented in Table 5.

Table 5. Recommended environmental conditions for a cycle

Week	Recommended temperature, ℃	Humidity, %
1	33	50 – 70
2	29	50 – 60
3	25	50 – 70
4	22	35 – 75
5	20	35 – 75
6	18	35 – 75
7	18	35 – 75
8*	18	35 – 75

**2007/43/CE*

The ventilation flow rate for air, required by Romanian legislation, was 0.007 $(m^3/s)/m^3$ for first week of growth and variable between 0.0028 and 0.0042 $(m^3/s)/m^3$ for the remaining weeks of the growth cycle, with higher flow rates as the birds mature.

In total, eight growth cycles were achieved, fully developed over one calendar year. The greatest difficulties are for the beginning of the year and the end of the year cycles, when the weather conditions are the harshest, with application to the climate of the Romanian Plain.

For each growth cycle, in correlation with the outside temperature and the degree of development of the birds, the required heat and fuel consumption were calculated respectively. Table 6 presented the fuel consumption for a year, separately for heating and ventilation, and the graph in Figure 15 highlights the evolution of total fuel consumption by monthly breakdown.

Table 6. Annual fuel consumption

Time / Fuel consumption	Annual period (month)											
	01	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**
For heated [t]	4,19	5,22	4,25	1,62	1,76	0,24	0,9	0,00	1,80	1,65	4,11	2,63
For ventilation [t]	4,25	2,4	3,37	4,09	1,0	0,33	0,80	0,00	1,17	4,10	2,53	4,75
Total [t]	8,44	7,62	4,62	5,77	2,76	0,57	0,70	0,00	2,97	5,75	6,69	7,38

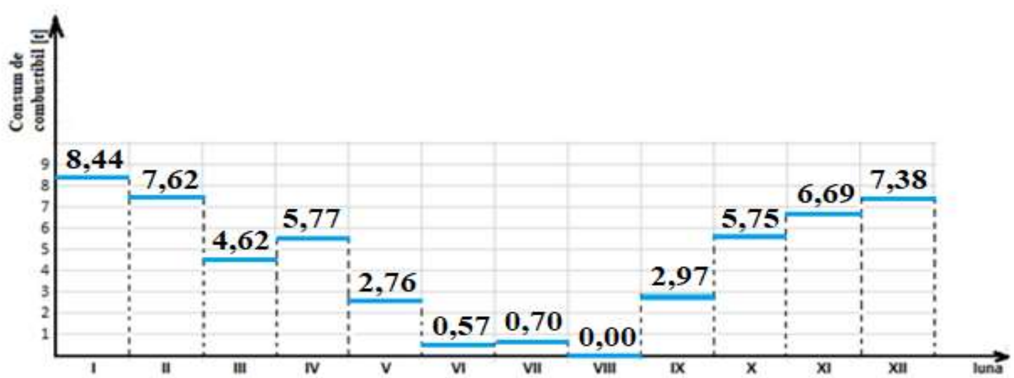


Fig. 15. Monthly variation of fuel consumption

For a 20% mixture of poultry manure with biomass, an annual consumption of 52.27 t resulted, of which 42.6 t of biomass and 10.67 t of poultry manure. According to the experimental combustion study, by increasing the participation of poultry manure to 30%, the annual amount of poultry manure increases to 16 t annually.

These quantities are below those generated by the breeding of birds, which for an average load of birds on the surface of the hall reaches 50.4 t per year.

In order to validate the calculation model, the data from Societatea Comercială Buturugeni - Giurgiu were used, where the air conditioning is carried out with a thermal power through heating elements with a radiator. It is found that the heat consumption in the calculation module is below that of the Buturugeni farm, built according to the norms of the 80s of the last century. It is stated that the average air flow for ventilation at the Buturugeni farm was below the current norms of the Ministry of Agriculture that were used in the developed model.

The computational model developed in the PhD thesis can be a model for technical application in the future.

Chapter 7, entitled *"General conclusions, original contributions and future perspectives"* includes:

1. General conclusions

The doctoral thesis entitled "Integrated Energetic and Ecological Recovery of Waste from the Poultry Sector" aligns with the research direction on transition operations to an energy system with the limitation of the greenhouse effect until 2050 (NZE2050), within the Sustainable Development Scenario. Aiming to meet the requirements of European legislation, the thesis proposes a theoretically and experimentally validated solution for energy and ecological recovery of bird waste.

The topic of the PhD thesis arose as a consequence of the high production of poultry meat, as well as the large quantities of related manure, which create significant problems of handling, storage and greening.

The main conclusions resulting from the research carried out during the elaboration of the thesis *"The Integrated Energetic and Ecological Valorization of Waste from the Poultry Sector"* are:

- According to the latest EU decisions, through the Paris Agreement of 2015, avian waste can be included in the biomass category, thus becoming a possible renewable fuel that can be integrated into a circular economy.
- Poultry manure were considered as part of agro-zootechnical waste, which can essentially contribute to the creation of a circular economy through combustion, the ash being neutral as a final product, but rich in phosphorus and calcium. Thus, it becomes a potential agricultural fertilizer. According to the Kyoto Agreement, the CO_2 emission is considered

zero, both for poultry manure and for solid biomass used as heat support (poultry manure, according to the Paris Agreement of 2015, are considered renewable sources of bioenergy).

- As a result of the analysis of the specific problems of intensive poultry production, which determine in particular energy and ventilation aspects necessary for industrial poultry production, the specific elements of this activity were presented, as the number of growing birds in relation to the surface unit, the amounts of resulting manure and the particularities of ventilation imposed related to the external temperature and the degree of maturity of the brood, and the microclimate recommendations were presented synthetically.
- The heat requirement was presented in detail, related both to the construction type of the poultry sheds and to the annual climate for a certain geographical position. The internal thermal factor, represented by the metabolism of the birds, was also introduced. Multiple data and requirements necessary for the construction and operation of a poultry complex were synthesized.
- A synthetic calculation model was created for the heating-ventilation process for a special construction hall, intended for breeding birds in Buturugeni, Giurgiu county. This application for an existing farm will allow the validation of the original calculation model for the air conditioning of a hall module through the co-combustion of poultry manure - solid biomass.
- Laboratory determinations revealed the existence of a very high humidity and a corresponding content of volatile matter. The lower calorific value was very low, in the range of 3800 – 6000 kJ/kg. A comparison of it with the values for other categories of solid fuels was also made.
- Starting from these characteristics for poultry manure, the performances of conversion technologies through thermal processing were analyzed, namely: gasification, pyrolysis and direct combustion.
- Regarding gasification, a case study was analyzed regarding a mixture of biomass – poultry manure, carried out for a pilot gasifier in Poland. Gasification led to the production of gasogen gas of low thermal power, but with very high specific costs.
- The pyrolysis of raw poultry manure was presented through the results of the research carried out within the Politehnica University of Bucharest, Department of Thermotechnics, which highlighted an efficient process from an energetic point of view, the resulting coke

as the final product being "clean" and with a higher potential energy than the global energy consumption required for pyrolysis. However, the disadvantages related to the process of feeding and handling non-ecological waste remain.

- Fixed bed direct combustion was analyzed in detail, a technology that will be further studied and experimental. Particular attention has been paid to the aerodynamics of the fuel bed, including the need to blow secondary air above the fuel bed, in order to reduce the emission of carbon monoxide, according to the latest ecological technologies.
- In the framework of the research on co-combustion of avian waste with biomass in a fixed layer, details were made on the particularities of this combustion technology, highlighting the achievements for complete combustion, especially for the case of high volume densities of the fuel layer, and it was presented the variation of the burning speed according to the density of the fuel layer.
- Pollutant emissions were initially studied from the point of view of their genesis. For the co-combustion experiments of poultry manure with woody biomass, a pilot boiler of 55 kW was used, intended for the production of residential heat, which was equipped with all the necessary measurement and control equipment. Avian waste had a mass contribution between 13% and 30% compared to woody or agricultural biomass. The combustion process was monitored sequentially over time. The resulting and recorded pollutant emissions were within the permitted limits. No NH_3 emissions were recorded, as a result of the combustion of this gaseous component in the ember layer. The power plant had a normal yield for such a fuel, confirming from this point of view the possible use of the fixed bed combustion technology for the mixture of biomass with poultry manure.
- After the extensive suite of experiments presented, it can be mentioned that this fixed bed combustion technology represents a positive solution, capable of being applied at an industrial level as well.
- A conceptual calculation model of the heating-ventilation process was created, based on the energy released by the co-combustion of poultry manure from the source with solid biomass. The fuel contained 20% avian waste and 80% solid biomass, an allowed proportion, based on the data from the research of the aforementioned laboratory experiments. The conceptual model was created based on the Romanian legislation for the poultry industry and was applied to a 1000 m^3 hall model. The results obtained can be

extended to any volume of intensive poultry production. Over the period of one year, six growth cycles of the birds were analyzed. The study covered a period of one year, for the temperate continental climate of Romania, Bucharest area. According to the growth cycle, the calendar year was divided into VI development cycles of eight weeks/cycle. It has been observed that not all of the manure is required for conditioning, resulting in a surplus of waste that must be directed to storage. It was possible to determine the biomass and avian waste required for the air conditioning of the respective calculation module. The resulting amount of avian waste was determined for that calculation module. The conceptual model developed was validated by reporting the data to those obtained at the S.C. Buturugeni – Giurgiu.

2. Original contributions of the doctoral thesis

Through the studies and research carried out, the doctoral thesis made the following contributions:

- determination of the energy characteristics for raw poultry manure and with biomass bed produced at two poultry farms in Romania (Buturugeni – Giurgiu and Titu – Dâmbovița) and ranking them against similar characteristics for solid biomass;
- determining the optimal composition according to the energy characteristics of the two components, poultry manure and solid biomass, for an efficient co-combustion in a fixed bed;
- highlighting the importance of the density of the fuel layer for achieving optimal aerodynamics of the air path; recommended dates were presented for this purpose;
- detailed experiments for the co-combustion of poultry manure – solid biomass (woody and agricultural) for mass fractions of poultry manure from 13% to 30%. The experiments were carried out on a pilot boiler of medium power (55 kW), intended for residential heating. The details of the experimental setup and its implementation technique are presented. The time sequences of the co-combustion process and the analysis of polluting emissions are edifying, finding that they fall within the limits of the legislation. The global efficiency of the boiler was also presented, which also has values in the field specific to its construction and operation technology.

- the development of a conceptual model for the air conditioning of a 1000 m^3 indoor module for the intensive breeding of birds, with the help of the co-combustion of the mixture consisting of 20% poultry manure from the source and 80% solid biomass, fuel defined and experimentally tested within Chapters 4 and 5. The conceptual model for calculating heating took into account the norms of the respective industry in our country and the climatic conditions in Romania (the Bucharest area was chosen) and included VI cycles of bird growth for a calendar year.
- the required annual consumption for the air conditioning of the respective calculation module, which includes heating and ventilation, was determined. The annual consumption of poultry waste was compared, which resulted below that produced by poultry farming.

3. Prospects for future research

The research results from the doctoral thesis lead to the following directions, in order to widen the application of heating the poultry breeding complexes, through a contribution as large as possible of avian waste:

- research on drying, at least partially, of poultry manure. An increase in the share of poultry manure in co-combustion with biomass can thus be achieved;
- research on co-combustion of avian waste with solid biomass of higher calorific value, obtained by briquetting and pelletizing;
- research on the pyrolysis of poultry manure, research started in the Politehnica University of Bucharest, and which should be continued on a pilot plant with a higher power, of at least 5 kW. The first results obtained have already demonstrated the existence of an integral pyrolysis-combustion process with a positive energy effect. It is mentioned that gasification, according to the data presented in the paper, produces a quantity of gas with a low calorific value, which does not have a positive energetic effect.

In conclusion, it follows that the research carried out in the PhD thesis has opened a path towards the use of these avian wastes by direct combustion for the dual purpose of energetic and ecological, but also new possible directions of applications related to other combustion technologies.

Keywords: poultry waste, solid biomass, co-combustion, fixed layer, circular energy.