ISSN 1407-7345 POWER AND ELECTRICAL ENGINEERING 2007-7345
ENERĢĒTIKA UN ELEKTROTEHNIKA

ENERGY SYSTEMS AND THE ENVIRONMENT
ENERGOSISTĒMAS UN VIDE

# EXPERIMENTAL STUDY OF MULTI-FUEL FIRING FOR EFFECTIVE AND ENVIRONMENTALLY FRIENDLY HEAT PRODUCTION

# DAUDZVEIDĪGU KURINĀMO VIENLAICĪGĀS SADEDZINĀŠANAS EKSPERIMENTĀLIE PĒTĪJUMI EFEKTĪVAI UN VIDEI DRAUDZĪGA SILTUMA RAŽOŠANAI

**Inesa Barmina,** head research, Dr.sc.ing.
University of Latvia, Institute of Physics
Address: Salaspils-1, Miera Street 32, LV-2169, Latvia;
Phone: 371+7945838 ;
e-mail: barmina@sal.lv

**Alexander Desnickis,** PhD student
Riga Technical University, Faculty of Power and electrical Engineering
Address: Kronvalda Boulevard 1, LV-1010, Riga, Latvia;
Phone: 371+29488674
e-mail: alexander.desnitsky@optron.lv

**Martins Gedrovičs,** Ass.Prof., Dr.sc.ing.
Riga Technical University, Faculty of Power and electrical Engineering
Address: Kronvalda boulevard 1, LV-1010, Riga, Latvia;
Phone: 371+7041659, Fax: 371+7041602
e-mail: martins.gedrovics@lg.lv

**Modris Purmals,** head ing.
University of Latvia, Institute of Physics
Address: Salaspils-1, Miera Street 32, LV-2169, Latvia
Phone: 371+26302915
e-mail: mzfi@sal.lv

**Maija Zaķe,** head researcher, Dr phys.
University of Latvia, Institute of Physics
Address: Salaspils-1, Miera Street 32, LV-2169, Latvia
Phone: 371+7945838
e-mail: mzfi@sal.lv

***Keywords: boiler, co-firing, heat production, firewood, furnace, propane, wood pellets***

## Introduction

Co-firing, the simultaneous combustion of renewable (wood biomass) with fossil fuels (coal, natural gas, fuel oil, etc.) in one boiler is an effective means for greenhouse gas mitigation, providing a low cost approach to increasing generation capacity for “green power” with a minimal modification of the existing equipment [1-3]. Irrespective of the success of different co-firing technologies at utility power plants, co-firing practice at industrial and non-utility boilers is quite limited, although co-firing allows reduce emissions of greenhouse gas $CO_2$, since renewable fuels are considered to be carbon-neutral. Moreover, co-firing so allows reduced $SO_2$ and $NO_x$ emissions, since wood biomass contains fewer amounts of sulfur and nitrogen. Consequently, co-firing technology helps meet goals for environmental protection.

Design and operation of boilers using more than one fuel for the heat energy production in different proportions offers a way to control combustion efficiency and composition of the products, but, in the same time, the variations in proportions require design considerations and a comparative experimental study of different techniques for multi-fuel firing, to provide the effective and green heat energy production for a wide range of proportions between the fuels, used for co-fire. The current paper presents results of an experimental study and design considerations for effective and environmentally friendly heat production by co-firing and the renewable fuel (wood pellets, firewood) with different proportions of fossil gaseous fuel (propane), especially applicable to supply space heating and domestic hot water needs.

## Experimental device

First, the experimental investigations of wood biomass co-firing with gas (propane) were carried out using a small-scale (3-5 kW) pilot device [4] to explore the feasibility of system configuration for co-fire of discrete portions of the wood biomass (wood pellets) with gas as fuel and feasibility of multi-fuel firing of gaseous or wood fuel with different proportions for the heat energy production. The configuration of the facility for co-firing the wood biomass (wood pellets) with propane flame flow in these investigations was based on the wall-fired gasifier by introducing the swirling propane flame into the wood fuel, as well into the flame of the volatiles. The mass load of wood pellets in the gasifier can be varied in a range from 500g up to 600g. Because of the fixed axial position of an orifice used for the injection of the propane flame into the gasifier, increasing the total mass load of the wood pellets in the gasifier results in a gradual increase of a distance between the inlet of the propane flame and top of the wood fuel, so increasing the mass of wood pellets that is subjected to unsteady heating and gasification with direct influence on the rate of release a volatile matter during the wood gasification. The primary and secondary airflows in these experiments were used to initiate the wood fuel gasification and provide complete burnout of the wood char and volatiles. The primary air below the wood layer was supplied at a rate up to 40-50 l/min, while the secondary swirling air flow above the wood biomass was supplied at a rate up to 60-70 l/min, completing burnout of the volatiles. The strong swirl of combustion air controls the flame stability and improves the local mixing of the flame compounds.

The next approach to biomass co-firing refers to comparative experimental investigations of firewood co-fire with gas (propane), providing the modification of a domestic gas boiler that is improved for co-firing firewood with propane flame at a rate up to 2,5 kJ/s and allows producing heat energy at a rate up to 10 kJ/s. The domestic gas boiler was integrated with a wood fuel furnace, using a primary air supply below the stoker grate, while the loop of secondary swirling air supply and the gas burner were located above the firewood, improving combustion of the volatile matter.

The experimental study of multi-fuel firing included the complex time-dependent measurements of the flame temperature, using Pt/Pt-Rh thermocouples, the flame composition, using gas analyzer Testo 350-XL and the rate of heat production, performing the calorimetric measurements of cooling water flow downstream the water-cooled channel sections. The measurements were carried out at different stages of propane co-fire, providing record of the data with a time interval of 1 sec. The data record is provided using the plate PC-20TR [5].

## Experimental results and discussion

Kinetic study of co-firing the discrete portions of wood pellets (up to 600g) with the propane flame flow has shown that at the initial stage of propane co-fire, when the propane flame acts as a heat source, the additional heat supply into the wood biomass at the rates 0,5-1,2 kJ/s results in an enhanced unsteady wood biomass drying, heating and gasification with an intensive release of the flammable volatiles - CO, $H_2$, $CH_4$. The rate of wood gasification at this stage of direct propane co-fire linearly depends on the rate of propane co-fire. To provide complete combustion of the volatiles, the air excess must support the enhanced release of volatiles. Therefore, the direct propane co-fire of the wood pellets is carried out at the air excess 35-40%. Combustion efficiency at this stage of propane co-fire is relatively high and reaches 88-92%, providing a rate of the heat release up to 2,9-3 kJ/s, while the temperature of the flame reaction zone approaches 1900-2000K with correlating increase up to the peak value of 16%-18% the mass fraction of main product - $CO_2$. The peak mass fraction of $CO_2$ in the products mostly (up to 82%) refers to the carbon-neutral emission, produced during the burnout of the renewable fuel- wood biomass, while the mass fraction of the greenhouse carbon emission, produced during the burnout of propane is limited by 18-20% from the total mass of carbon emissions. It should be noted that, as a consequence of the enhanced wood fuel gasification and burnout of the volatiles at this stage of propane co-fire, the high temperature levels in the flame reaction zone promotes the formation of $NO_x$ ($NO+N_2O$) emissions in the products up to the peak value- 100-110 ppm that mostly (up to 98%) refers to the formation of thermal NO emission.

The rate of wood gasification, composition of the products and the total heat energy produced downstream the combustor are very sensitive to the variations of a moisture content in the wood fuel- the higher moisture content results in a linear decrease of the heating value of the wood fuel, so decreasing the rate of wood gasification, combustion efficiency and the total heat energy produced in the combustor. Therefore, to provide a constant rate of heat production in the combustor, higher moisture content in the wood fuel must be supported by a higher rate of propane co-fire. The results of the experimental study of the rate of heat production at different moisture contents in the wood fuel have shown that increasing the moisture content in the wood fuel up to 40% constant rate of the heat production in the combustor can be provided by increasing the rate of propane co-fire up to 1,2 kJ/s.

Finally, the results of the experimental study have shown that higher mass fraction of a volatile matter (CO, $H_2$) released above the wood layer and higher rate of a heat release downstream the combustor can be obtained by increasing the mass of the wood fuel, subjected to the direct propane co-fire. For a given geometry of the combustor and constant rate of propane co-fire (0,9 kJ/s) the enhanced release of the volatile matter with an increased rate of the heat production up to the peak value is fixed by increasing the mass load of the wood pellets above the inlet of propane flame up to 50-60 g, while a depth of the wood layer above the inlet of propane flame reaches 3 cm (Fig.1). At higher mass load of the wood pellets above the inlet of propane flame the mass fraction of volatile matter and the rate of the heat production in the combustor starts to decrease because the penetration of the hot volatiles through the porous layer of the wood pellets results in an intensive heat exchange between the compounds. As a result, the temperature of volatiles, penetrating downstream the wood layer, gradually decreases. Therefore, increasing of a mass load of wood fuel gradually slows down the rate of wood fuel heating and gasification and promotes ignition delay. Actually, a strong balance is detected between the rate of additional heat supply during the propane co-fire and rate of the heat consumption downstream the layer of the wood pellets, determining the formation of peak mass fraction of released volatiles and the peak value of total amount of heat produced in the combustor by increasing the mass load of wood pellets above the inlet of the propane flame (Fig.1).

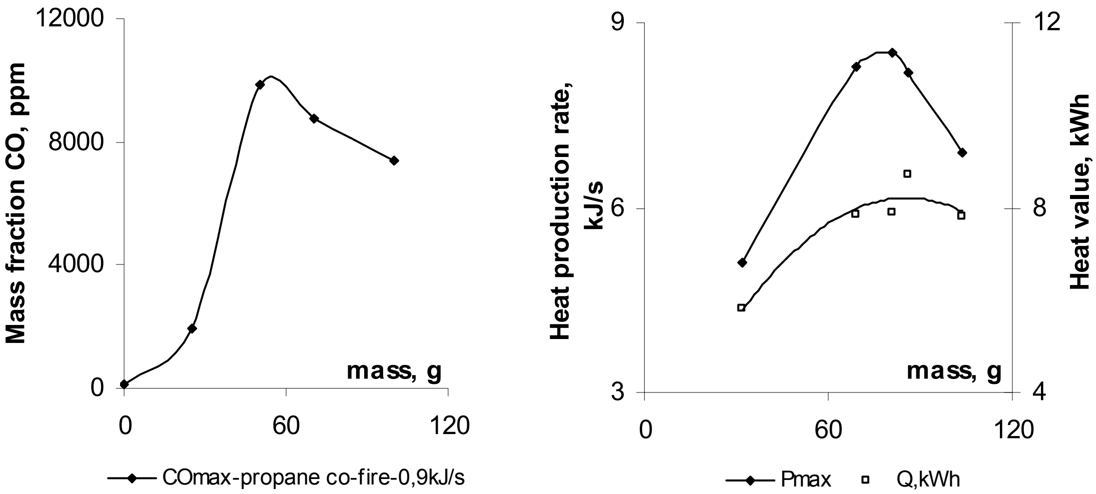


Figure 1. The effect of a mass load of the wood pellets above the inlet of the propane flame on the rate of a release of CO, rate of a heat production and heat amount produced in the combustor.

Because of enhanced gasification of the discrete portions of wood pellets and burnout of the volatiles, the top of unburned wood layer gradually slows down below the inlet of the propane flame, promoting transition to the next stage of propane co-fire- the direct propane co-fire of volatile matter. During this stage of propane co-fire the propane flame is injected into the flame of volatiles, completing combustion of the volatile matter and, therefore, decreasing to the minimum value (40-200ppm) the mass fraction of CO emissions in the products. At a constant rate of propane co-fire (0,9 kJ/s) the rate of reactions and flame temperature at this stage of propane co-fire is controlled by the rate of self-sustaining gasification of the wood pellets. The gradual transition to the low-temperature self-sustaining gasification of the wood biomass results in a reduced rate of wood gasification with correlating decrease of the rate of reactions and flame temperature. The rate of the heat production during the burnout of volatiles falls below 1,5 kJ/s, combustion efficiency decreases to 78-82 %, the flame temperature falls to 1700-1750 K, while the mass fraction of $CO_2$ in the products during this stage of propane co-fire decreases to 10-12 %. The gradual reduction in flame temperature at the outlet of gasifier also succeeds in decreasing the rate of thermal NO formation. The $NO_x$ levels in the products decreases to acceptable limits 70-75 ppm at air excess 80-100%, producing the low-temperature staged, while cleaner burnout of the wood fuel. Hence, the main advantage of co-firing the renewable with fossil fuel by replacing a part of fossil fuel by a renewable one can be related to environmental protection.
The results presented above mostly refer to the experimental study of co-fire the wood pellets with propane. Wood fuel resources available for co-firing are very different (firewood, pellets, sawdust, briquettes, etc.) with different sizes, bulk density and moisture content in the wood biomass. Because of widespread utilization of firewood with different levels of moisture in heating private houses, the comparative experimental studies of moist firewood co-fire with propane are carried out. In order to illustrate the effect of propane co-fire on the burnout of firewood with application to domestic heating, experimental tests are carried out in modified domestic utility stoker boiler, providing control of the burnout of discrete portions of firewood

(up to 4 kg) at different rates of propane co-fire (1,5-2,5 kJ/s) and different rates of air supply into the furnace. The propane flame flow in these investigations is injected above the layer of the wood fuel- into the flame of volatiles, completing combustion of volatile matter, while the gasification of wood fuel and ignition of the volatiles is initiated below the wood layer by using the external heat source. By analogy with the enhanced formation of volatile matter in the small-scale pilot device, when an ignition source- propane flame flow is injected directly into the wood fuel (Fig.1), the external heat source promotes the enhanced gasification of firewood with an intensive release of volatile matter (CO, $H_2$). During the primary stage of firewood gasification the mass fraction of CO in the products is relatively high and approaches 5000-7900ppm. The propane co-fire enhances the burnout of the volatiles with pronounced increase of the rate of heat production in a furnace and mass fraction of $CO_2$ in the products, promoting a correlating decrease of the mass fraction of free hydrogen and CO in the products (Fig.2). Similar as with co-fire of the wood pellets, the burnout of the volatiles downstream the flame reaction zone requires the air excess supply into the furnace. At a rate of propane co-fire 1,7 kJ/s the most intensive burnout of the volatiles is observed for the conditions, when the primary air supply below the grate approaches to 80 l/min, while the secondary air supply above the firewood is limited by 8 l/min. The enhanced burnout of the volatiles for such conditions results in an increase of the net mass fraction of $CO_2$ emissions in the products up to 10%, while the peak values of $NO_x$ emissions during the propane co-fire of firewood approaches 100-120ppm. The net release of $NO_x$ emissions mostly refers to the formation of temperature-sensitive NO emissions, while the net release of $NO_2$ during the burnout of volatiles is about 4,1-4,5ppm and does not exceed 10-12% from the net amount of produced $NO_x$ emissions. By increasing the moisture content in the firewood and decreasing the rate of propane co-fire is observed ignition delay, decreasing the flame temperature and net amount of produced $CO_2$ emissions below 10%. The investigations of the effect of propane co-fire on the burnout of damp firewood have shown that at the gas co-fire of the damp firewood is successful at the rates of propane co-fire 1,5-2,5 kJ/s and moisture content in firewood up 35% and has the advantage of better control over burnout rates and composition of polluting emissions.

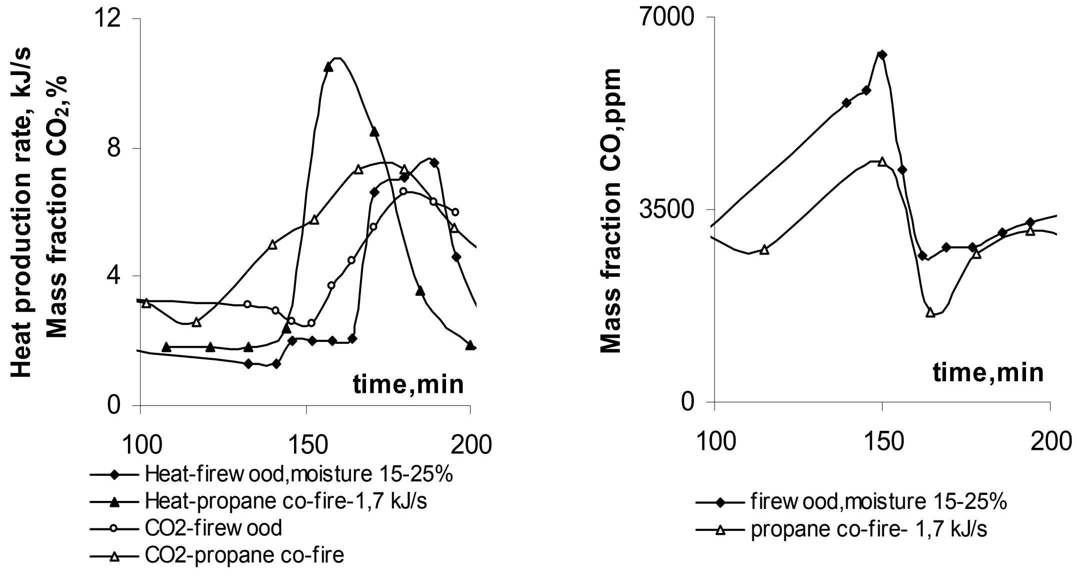


Figure 2. The time-dependent variations of the heat production rate and composition of polluting emissions at a rate of propane co-fire 1,7 kJ/s, rate of total air supply into the furnace 88 l/min and moisture content in the firewood 15-25%.

## References


1. J.E. Fehrs, C.T. Donovan, Co-firing Wood in Coal-fired Industrial Stoker Boilers, Northeast Regional Biomass Program, Washington, D.C., http://www.nrbp.org/pdfs/pub18.pdf, 1999, 1-31.

2. J. Woods, R. Tipper, G. Brown, R. Diaz-Chavez, J. Lovell and P. de Groot, Evaluating the Sustainability of Co-firing in the UK, Report of Themba Technology Ltd and Edinburgh Centre for Carbon Management, Nr. URN 06/1960, London, 2006, 1-46.

3. E. Hughes, Biomass Cofiring with Natural Gas in California, Technical Progress, http://www.energy.ca.gov./pier/final_project_reports/500-02-050.html, 2000.

4. M. Zaķe, I. Barmina, M. Gedrovičs, A. Desņickis, Effective Technique of Wood and Gaseous Fuel Co-firing for Clean Energy Production, Latvian Journal of Phys. and Techn. Sci., 2007, N2, p.17.



***Barmina I., Desņickis A., Gedrovičs M., Purmals M., Zaķe M. Daudzveidīgu kurināmo vienlaicīgās sadedzināšanas eksperimentālie pētījumi efektīvai un videi draudzīga siltuma ražošanai.***

*Eksperimentāli pētīts kombinētais gāzveida fosilā kurināmā (propāna) un dažāda veida cietā atjaunojamā kurināmā (koka granulu, malkas) degšanas process, lai nodrošinātu intensīvu un stabilu koksnes biomasas degšanas procesu, ierobežojot papildus pievadītā siltuma daudzumu kombinētā degšanas procesā līdz 25% no kopējā saražotā siltuma daudzuma iekārtā. Eksperimentālo pētījumu rezultāti apliecina, ka kombinētā degšanas procesa efektivitāte un degšanas produktu sastāvs ir būtiski atkarīgs no propāna liesmas ievadīšanas veida gazifikatorā. Ievadot propāna liesmu granulu slānī, tiek nodrošināta intensīva koksnes gazifikācija, palielinot siltuma ražošanas ātrumu un efektivitāti. Mazāk efektīvu, bet tīrāku siltuma ražošanu var nodrošināt, ievadot propāna liesmu gaistošo savienojumu degšanas zonā. Līdzīgi rezultāti ir iegūti, veidojot kombinēto degšanas procesu krāsnī, kurā tiek dedzināta malka. Ja papildus pievadītā siltuma daudzums kombinētā degšanas procesā ir ierobežots līdz 25% no kopējā saražotā siltuma daudzuma, kombinētais degšanas process ļauj nodrošināt pilnīgāku gaistošo savienojumu sadedzināšanu, samazinot CO un $NO_x$ emisiju un nodrošinot dominējošu (līdz 82%) neitrālā oglekļa dioksīda ($CO_2$) veidošanos atjaunojamā kurināmā degšanas procesā.*



***Barmina I., Desnickis A., Gedrovics M., Purmals M., Zake M., Experimental Study of Multi-fuel Firing for the Effective and Environmentally Friendly Heat Production.***

*The experimental study of fossil fuel (propane) co-firing with renewable (wood pellets, firewood) is carried out with the aim to provide an intensive and stable burnout of the wood biomass by limiting the rate of propane co-fire at 25% from the total average produced heat. The results of experimental investigations have shown that effect of propane co-fire on the rate of heat production and composition of polluting emissions depends on the mode of propane flame injection into the gasifier. The enhanced gasification of the wood biomass with an increased rate of heat production and efficiency of the heat production has been observed for the direct propane flame flow injection into the wood biomass. The less effective, while cleaner heat production can be observed for the direct propane co-fire of the volatiles. Similar effects of propane co-fire on the rate of heat production and composition of the products are observed by co-firing the firewood with the propane flame flow. The propane co-fire of firewood at a rate up to 25% results in a more effective and cleaner burnout of the wood fuel with reduced mass fraction of polluting (CO, NO) emissions in the products and dominant release of carbon –neutral $CO_2$ emissions.*



***Бармина И., Десницкий А., Гедрович М., Пурмалс М., Заке М., Экспериментальные исследования по комбинированному сжиганию разнообразного вида топлива для производства эффективного и экологически чистого тепла.***

*Экспериментальные исследования по комбинированному сжиганию природного топлива (пропана) с возобновляемым (древесные гранулы, дрова) проведены с целью осуществить эффективный и экологически чистый процесс производства тепла. Дополнительное тепло, подводимое к древесине пламенем пропана, не*

*превышает 25% от общего тепла, выделяющегося в процессе комбинированного сжигания. Результаты исследований показывают, что эффективность процесса горения и состав продуктов сгорания существенно зависят от способа подачи пламени пропана в газификатор. Подвод пламени пропана в слой гранул интенсифицирует газификацию древесины, увеличивает теплопроизводительность и эффективность горения. Менее эффективное, но более чистое производство тепла можно обеспечить подводом дополнительного потока тепла к зоне горения летучих веществ. Аналогичные результаты получены при сжигании дров с пропаном в печи. Комбинированное горение дров с ограниченным подводом дополнительного тепла от пламени пропана (до 25% тепла) обеспечивает более эффективное и чистое сжигание дров с уменьшенным содержанием CO и $NO_x$ в продуктах сгорания. Кроме того, образующийся в процессе горения возобновляемого топлива диоксид углерода ($CO_2$) является в основном (до 82%) нейтральным.*