# ENERGY EFFICIENCY IN REFUSE DERIVED FUEL UTILIZATION

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**Abstract.** Refuse derived fuel (RDF) derived from municipal solid waste (MSW) is an issue of essential consideration for the sustainable management of the waste-to-energy concept. The policy of waste management in Bulgaria is based on the implementation of leading technologies for waste utilization. In the framework of the recent Programme period 2014-2020 of the European Union, an installation for mechanical and biological treatment of municipal solid waste (MSW) have to be constructed in Sofia, which principal product is RDF. Within the same period an installation for RDF derived energy utilization must be implemented at the district heating company "Toplofikacia Sofia EAD", where an electricity and heat cogeneration technology is considered. The present work, aims at obtaining the efficiency of cogeneration in contrast to the conditions of electricity and heat separate production. Thus, the high energy efficiency criterion ($\Delta F > 10\%$) was determined, which justifies the choice of the cogeneration technology instead of production of heat only. At present, Toplofikacia Sofia EAD uses mainly natural gas and fuel diversification is required. The implementation of an installation for RDF utilization ensures the fuel diversification for a reasonable period of time, according to the estimated potential of RDF implementation for energy production.

**Keywords**: waste to energy, refuse derived fuel, cogeneration of electricity and heat

## 1. Introduction

Last decades, the society worldwide is facing social and economic problems, which greatly influence the population's quality of life in terms of the continuously increasing power demand, the dependence on energy imports and limited primary fuel resources as well as the economic crises. This implies the necessity of implementing activities assuring the energy efficiency, part of which is the development of intelligent waste management policy [1-5].

The RDF has a considerable potential as fuel resource because it is typically produced by shredding, dehydrating and if necessary biological treatment of the combustible components of MSW [5]. The quality and the applicability limits of the RDF strongly depend on the choice of waste converting technology [6-9] and the MSW composition [10-12]. Different aspects of the waste-to-energy concept have been widely studied within the last decades. Nowadays, these technologies are significantly developed, modernized and diversified considering the available feedstock, the origin's restrictions and the regulation policy controlling the choice of appropriate processing technology [13-16]. The RDF is typically used for electricity, heat or mechanical energy generation often applied as cogeneration process. It is greatly valued for its primary energy savings, and its potential for reducing the carbon emissions from stationary combustion systems according to the EU Emissions Trading System (EU ETS) [17, 18].

Since Bulgaria joined the European Union, numerous activities have been issued concerning the cohesion of waste treatment and waste management policy [1, 2]. Measures were undertaken concerning the landfill gas (LFG) recovery, and the first installation for LFG utilization with electricity production is in operation [19, 20].

In 2014 starts the construction of the first plant for mechanical and biological treatment of municipal waste matter in Sofia, Bulgaria [1, 4]. The main issues are the production of RDF and its further utilization in the energy sector. The RDF is an alternative local energy supply fuel considered as a renewable energy resource, because most of it is planned to be produced from biologically degradable refuse. Currently, a project for electricity and heat cogeneration through RDF utilization is being implemented at Toplofikacia Sofia EAD. The installation is described in [21], revealing the specific project parameters for its implementation at the largest district heating plant in the region. Some key advantages of this project [21] are: the opportunity for RDF production in the region of Sofia city, the assured consumption of the generated electricity and heat during the whole year and the fact that the waste treatment plant, and Toplofikacia Sofia EAD are in possession of Sofia Municipality. This is the first attempt for diversification of the primary fuel supply for district heating in the country and the energy efficiency has to be estimated.

The goal of this study is to estimate the efficiency of the installation for electricity and heat cogeneration through RDF utilization [21]. For that purpose, several key parameters were investigated, considering the characteristics of the RDF installation chosen for implementation at Toplofikacia Sofia EAD as described in [21]. The energy efficiency and the primary energy savings through

the RDF utilization is considered. The results determined significant primary energy savings in terms of the originally used fuel (natural gas).

## 2. Methods

The energy efficiency and the primary energy savings from RDF utilization were obtained applying the methodologies described in Annex II of the Directive of the EU on the energy efficiency [22] and the Ordinance of the Ministry of economy and energy of Bulgaria [23]. For that purpose, the operating parameters of the installation presented in [21] were considered. Details about the implemented and applied mathematical approach are provided further in the text.

## 3. Results and discussion

### 3.1. Gross heat production from RDF utilization

The gross annual heat production was estimated considering basic operation conditions of Toplofikacia Sofia EAD according to [21]. The plant's availability considered in [21] is 8,000 h/year at an expected rate of RDF production ($B$) is 180,000 t/year or 22.5 t/h and the estimated low heat value (LHV) of the RDF ($Q_i^r$) is 13 GJ/t, because it is found to vary between 12 - 14 MJ/kg. The gross annual heat production from RDF utilization can be calculated through the equation

$$Q = B \cdot Q_i^r . \quad (1)$$

The gross heat production ($Q$) was obtained about 650 GWh/year.

Often the LHV of a fuel is expressed in terms of coal equivalent as a reference unit for the evaluation of different energy carriers. Accordingly, a kilogram of coal equivalent corresponds to 7,000 kilocalories. Considering the fact that 7,000 kcal are about 29.3 MJ or 8.141 kWh, the net calorific value or LHV of a ton of coal equivalent is 29.3 GJ/t. Thus, the annual consumption of RDF at Toplofikacia Sofia EAD in terms of tons of coal equivalent was obtained about 80,000 t/year.

### 3.2. Total energy efficiency

The total energy efficiency of electricity and heat cogeneration ($\eta_{total}$) of the installation for RDF utilization suggested in [21] was expressed through equation (2). This approach was adopted from [23]:

$$\eta_{total} = \frac{E_{gross} + Q_{combined}}{\sum_{i=1}^{n} B_i \cdot Q_i^r}, \quad (2)$$

where

$E_{gross}$ – gross annual electricity production (156 GWh),

$Q_{combined}$ – gross useful heat demand, annually produced in cogeneration conditions (442 GWh),

$B_i$ – rate of RDF utilization for the same period of time in tones, reduced with the amount of fuel used for producing the useful heat demand in non-cogeneration conditions (180,000 t/year),

$Q_i^r$ – net calorific value or LHV of the RDF for the same period of time (13 GJ/t),

$n$ – number of the used fuels, in this particular case it was equal to 1.

Thus, the total energy efficiency of electricity and heat cogeneration was estimated about 92 %.

The prognostic value of the RDF consumption rate in terms of coal equivalent was obtained about 270 g/kWh, which is a bit higher than the reported value using only natural gas [24]. It was observed, that the difference is due to the choice of the appropriate methodology for estimating the fuel distribution for electricity and heat production. Accordingly, the fuel consumption rate for heat production was obtained about 85 kg/MWh of coal equivalent, whereas the same parameter is reported as 132 kg/MWh [24]. Therefore, the primary energy savings had to be estimated.

### 3.3. Primary energy savings

Toplofikacia Sofia EAD is one of the largest district heating companies in Eastern Europe. The electricity is usually produced in combination with the heat, where only the domestic hot water generation is in continuous regime. In 2012, the plant reported [24] an annual consumption of natural gas about $7.5\times10^8$ N·m$^3$/year and gross heat production about 6,952 GWh. Transformed in terms of tons of coal equivalent, the annual fuel consumption is $854\times10^3$ t/year [25]. Thus, the mean annual electricity generation is about 800 GWh [24].

The present study aims at investigating the possibility for fuel diversification through the implementation of the installation for RDF utilization [21]. For that purpose, the total amount of electricity production from RDF utilization was estimated. The calculations are based on the above described annual fuel consumption of $854\times10^3$ t/year of coal equivalent and the amount of RDF, expected to be delivered to the plant, equal to 80 t/year of coal equivalent, which is about 9.4 % of the total annual fuel consumption [24]. The expected gross annual production of electricity from

RDF is 156 GWh or 146 GWh as net, at mean electricity utilization of the plant about 800 GWh per year. This indicates that at least 18 % of the electricity can be produced from RDF.

Highly efficient cogeneration is assumed, if at least 10 % of the primary energy savings are determined in comparison with the references for separate production of electricity and heat [22, 23].

In this particular investigation, the primary energy savings ($\Delta F$) was estimated for the case of electricity and heat cogeneration through RDF utilization at Toplofikacia Sofia EAD. The calculations were carried out in compliance with the methodology described in the Annex II of the Directive 2012/27/EC and the Ordinance РД-16-267 [22 and 23]. The parameter $\Delta F$ was obtained through the equation:

$$\Delta F = \left[1 - \frac{1}{\frac{\eta_e}{\eta_{Re}} - \frac{\eta_q}{\eta_{Rq}}}\right] \cdot 100, \qquad (3)$$

where

$\eta_e$ – electricity efficiency coefficient of the cogeneration production. It is usually obtained as the ratio between the annual electricity produced on cogeneration and the fuel input used to produce the sum of useful heat output and electricity from cogeneration (23.97 %),

$\eta_{Re}$ – efficiency reference value for separate electricity production (24.00 %),

$\eta_q$ – heat efficiency of the cogeneration process, which is the ratio of the annual useful heat output divided by the fuel input used to produce the sum of useful heat output and electricity from cogeneration, (68.09 %),

$\eta_{Rq}$ – efficiency reference value for separate heat production (80.00 %).

Thus, the total energy efficiency of electricity and heat cogeneration was estimated about 92 %.

The results obtained through the equation (3) showed considerable primary energy savings ($\Delta F$ = 45.94 %). Thus, the production of electricity and heat through RDF utilization at the considered installation complies with the preliminary defined requirements of the European Union [22] assuring satisfactory economy of primary energy resource.

## 4. Conclusions

The primary energy savings (about 46%) was estimated. The results confirmed high energy efficiency of the installation for RDF utilization [21], which justifies the choice of the complex cogeneration technology in comparison to the case of heat generation only. It is worth noticing, that in parallel to the installations operating with conventional fuel, the RDF installations typically operate at significantly lower parameters, in terms of pre-heated steam. The lower efficiency of electricity generation is then compensated by the increased boiler's exploitation cycle due to significantly reduced rate of high temperature corrosion.

The district heating company in question operates mainly with natural gas. Currently, more than 85 % of the natural gas in the country is imported, which requires urgent measures for fuel diversification. The RDF is an appropriate alternative and its utilization is expected to deliver about 10 % of the annually produced heat and about 18 % of the annual electricity production at Toplofikacia Sofia EAD. This allows the installation for RDF utilization to operate at basic load of 8000 h/year. Moreover, during the summer term only the RDF installation should be in use, ensuring hot water for nearly 2/3 of the population in Sofia city.

The results of this investigation confirmed that the chosen type of the installation for electricity and heat cogeneration through RDF utilization is appropriate for Toplofikacia Sofia EAD. The major benefit of this measure is the opportunity for fuel diversification, offering a sustainable solution to the MSW utilization problem for a reasonable period of time at the capital city of Bulgaria.

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