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Research Article

Evaluating the consumption of energy sources for rose oil production

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Abstract

The evaluation is related to two installations for water-steam distillation in a capacity of around 10 t rose flowers in case of 24-hour operation. It was specified that the specific consumptions per 1 kg processed rose flowers are as follow: 4 kg/kg for steam, 8 MJ/kg for heat energy, 0.26 kg/kg for natural gas (PNG and CNG), 0.28 kg/kg for LPG, 0.31 kg/kg for fuel oil, 0.90 kg/kg for wood pellets, 1.54 kg/kg for wood chips, 107 kJ/kg for electric energy, 10 L/kg for cooling water and 4.2 L/kg for tap water. The specific consumptions per 1 kg produced rose oil are about 14 t/kg for steam, 29 GJ/kg for heat energy, 914 kg/kg for natural gas, 982 kg/kg for LPG, 1080 kg/kg for fuel oil, 3196 kg/kg for wood pellets and 16301 kg/kg for wood chips. The costed shares related to the price of 1 kg rose oil are as follow: 21.4 % in case of using fuel oil, 13.9 % for LPG, 9.9 % for PNG, 9.7 % for CNG, 7 % for wood pellets, 4 % for wood chips; 0.32 % for tap water and 0.17 % for electrical energy.

Keywords: essential oils, specific energy consumption, energy efficiency, steam, fuel, biofuel, cooling water

Abbreviations:

CNG - Compressed Natural Gas
LPG - Liquefied Petroleum Gas
PNG - Piped Natural Gas

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Introduction

In recent years, the rose oil production in the world grows steadily, reaching over 6.2 t in 2018. In addition to the traditional producer countries as Bulgaria, Turkey, Iran and Morocco, there are also quite lots of new manufacturers from China, Afghanistan, Saudi Arabia and Azerbaijan. Rose oil production is a traditional production in Bulgaria, which has seen significant growth in recent years and reached 3.2 t in 2018. The average price of the exported Bulgarian rose oil reached almost 12500 EUR/kg in 2016 and it decreases gradually since then. A significant share of the end price of rose oil is the cost of energy, and especially fuel. Previous studies (Akterian 2001; Valchev et al. 2002) have estimated the consumption of steam and heat for the production of some essential oils. The specific heat consumption of water-steam distillation of rose flowers was found to be dozens of times higher than that of steam distillation.

Traditional technology for producing rose oil. The traditional flow diagram for processing rose flowers includes two successive stages (Baser and Buchbauer 2010; Chipiga 1981; Stoyanova and Georgiev 2007): (A) Water-steam distillation of flowers and (B) Re-distillation (cohobation) of distillate water, obtained in the first stage. The distillation itself comprises the following operations: (i) Heating the mixture of water and flowers to boiling; (ii) Steam distillation with evaporating distillation vapours including steam and vapours of aromatic components; (iii) Condensation of these distillation vapours and cooling the obtained distillate to 30°C; (iii) Gravity separation of light essential oil from heavy distillate water. The cohobation itself includes: (i) Heating of distillate water to boiling and subsequently emitting secondary distillation vapours; (ii) The latter are condensed and then the distillate is cooled to 30°C; (iii) Separating light secondary rose oil from heavy distillate water. The latter is passed for repeating cohobation.

Specific energy consumptions. Their values for manufacturing agricultural products vary from 0.4 to 66 MJ/kg (Kempen and Kraenzlein 2008). Pahlavan et al. (2012) specified that the specific energy consumption for producing rose flowers in Iran is 24.2 MJ/kg at an average yield of 280 kg/dka. The total specific energy consumption for manufacturing food products varies from 7 to 226 MJ/kg (Monforti-Ferrario and Pinedo-Pascua 2015). The higher energy consumption for manufacturing bread (11.2 MJ/kg) is related to the high temperature (200-300°C) during its baking and for cheese making (42.1 MJ/kg) – with the high value of cheese yield – about 10. The specific energy consumptions in chemical industry vary from 3 to 45 MJ/kg (De Beer 2000) and in the metallurgy – from 20 MJ/kg (for steal) to 65 MJ/kg (for aluminium) (Moya et al. 2015). The average specific energy for fabricating Uranium fuel (in which U-235 is enriched from 0.7% to 4%) is 2 GJ/kg (Lenzen 2008). The specific comminution energy for gold extraction vary from 45 to 175 GJ/kg (Ballantyne and Powell 2014; Fei-Baffoe et al. 2013). Gold ores what are reasonable for commercialization contain 1-5 ppm gold. Here it can be stated that the very high specific energy consumption for primary gold production is related with the very low gold concentration in the raw materials – ores.

The present study aims to specify the consumptions of steam, fuels for steam generation, cooling water, tap water and electric energy during the processing of rose flowers according to the traditional technology. The additional tasks were also determining their specific consumptions related to 1 kg processed rose flowers and to 1 kg produced rose oil; their costed share related to the price of the final product.

Materials and Methods

Distillation installations. They include several distillation units and a cohobation unit. The objects of the current study are two variants of an installation for processing rose flowers. The first variant includes two distillation units with a batch distiller with a capacity of 5.5 m^3 and a cohobation unit with a throughput rate 2400 L/h distillate water. The second variant comprises four distillation units with a batch distiller with a capacity of 3 m^3 and a cohobation unit with the same throughput. These variants are typical for small Bulgarian distilleries. These sets are suitable for full processing distillate waters, outgoing from the distillation units. The rate of distillation in this batch apparatuses is 8-10%/h, related to its working volume. The process duration is 2-2.5 h (Stoyanova and Georgiev 2007). The oil yield varies from 2.5 to 6 t rose flowers for producing 1 kg rose oil.

The consumption of steam used in apparatuses for distillation and cohobation. It was calculated on the base of heat balance with taking into account the masses of raw plant material, water filling, metal body, thermal isolation and 3% losses in the environment. The apparatuses were supplied with saturated steam at 8 bar pressure of steam boiler. For evaluating the heat equivalent of 1 kg steam, the specific latent heat 2047.3 kJ/kg for condensation of saturated steam at 8 bar pressure was taken into account.

Fuels, used for steam production. The objects of current analysis were as the fuels traditionally used in essential-oils sector: fuel oil (naphtha), natural gas (PNG - Piped Natural Gas and CNG - Compressed Natural Gas), LPG - Liquefied Petroleum Gas, so and alternative biofuels: wood pellets and wood chips. In Table 1 the heating values released during their combustion (Haynes 2017) and their prices with VAT in mid-2019 are presented. The prices of traditional fossil fuels (fuel oil, LPG and CNG) are according to the website https://fuelo.net for the period May-June 2019 without delivery. The price of PNG with delivery is by Citygas Bulgaria Plc for small consumer in the period after 1 July 2019. The Citygas operates in the regions of Plovdiv and Stara Zagora as well. The biofuels - wood pellets and chips – are not yet market regulated. There is a wide variety depending on the raw materials used, their derivation, humidity and processing. Their prices were collected in the Internet and they vary over a larger range. The fuel consumption was evaluated taking into account (i) the assumed coefficient of efficiency of steam boiler: 75 % in case of usage of biofuels; 90 % - for gaseous and liquid fossil fuels; 95 % - in case of using electric energy; (ii) the specific heat of fuel combustion, pointed in the Table 1.

Electric energy. Its consumption is in three main directions for: (i) cooling the wasted cooling water; (ii) water pumping from wells and supplying cooling water; (iii) other processing and services in the distillery. The used cooling water is outflowed from heat exchangers at temperature of 80°C. This

Table 1. Heating value and the price of some fuels in mid-2019

Energy source, fuel	Lower heating value, MJ/kg	Density, kg/m^3	Price
PNG	50.0	0.6682	107.292 BGL/MWh
CNG	(34.1 MJ/nm^3)	0.6682	1.45 BGL/kg
LPG	46.1	510	0.99 BGL/L
Fuel oil	41.9	830-860-890	2.33 BGL/L
Wood chips	10.0	250-300	0.04-0.10-0.12 BGL/kg
Wood pellets	15.0-17.0-18.7	500-600	0.22-0.30-0.50 BGL/kg
Electric energy	-	-	245.65 BGL kWh

The density of PNG and CNG are related to 1 nm^3 at 101.3 kPa pressure and 0 °C temperature.

water must be cooled by cooling towers at least to 40°C before their release in river or canal. For cooling such hot water with a flow rate of 5 m^3/h, a heat flow of 232.8 kW should be rejected. According to some researches (Halim 2015; LJ Energy Pte 2015) and the technical specifications of manufactures (Eko zora Ltd, Bulgaria; SPX Cooling Technologies UK Ltd) the specific electrical energy consumption of cooling tower for rejecting 1 kW heat flow vary from 4.3 to 17 W/kW. In the following calculations an average value of 8.5 W/kW, pointed by LJ Energy Pte (2015), was assumed. The specific energy consumption for pumping and supplying cooling water was evaluated on the base of the following assumptions: (i) the head of well pump is 40 mH$_2$0 and the water is pumped from a well of depth 20 m (typical for Southern Bulgaria); (ii) the efficiency of pump is 0.6; (iii) the pump runs at a constant flow rate around the clock. If 100 m^3 water is used for 24-hour operation, then the work for its pumping will be 65.4 MJ. The price of electric energy supplied by EVN Bulgaria AG, pointed in the Table 1, includes delivery, excise and VAT. This price is for business customers from the regulated market with one price scale, for low voltage for the period after July 1, 2019.

Cooling water. Its consumption was evaluated taking into account the following assumptions: the temperatures of fresh and exhaust cooling water is 20 °C and 80°C, respectively; the temperature of distillate discharged is 30°C.

Tap water. Its price (including supplying, waste disposal & its processing and VAT for industrial purposes) is 2.32/2.96 BGL/m^3. These prices are by the supplier V&K Ltd, Plovdiv as the first price is related to processing of waste water with the lowest degree of pollution and the second price – for the highest degree.

The costed shares of energy expenses. They were evaluated as a ratio between each energy expenses for 24-hour operation and the market price of the final product – rose oil produced for this period of time. Hitherto only rose oil of vintage 2018 is still being purchased for the price of 6500-7000 EUR/kg. In the next calculations, more reasonable price for manufacturers of 7000 EUR/kg or 13692 BGN/kg was assumed.

Results and Discussion

Results

General calculations for two installations studied. For bulk density of 110 kg/m^3 rose flowers in distiller, the mass of processed flowers for a batch cycle is 600 kg and 330 kg, respectively in 5.5 m^3 distiller and 3 m^3 one. The duration of operation cycle in the distillation apparatus is 3 h, including 2 h for steam distillation, 0.5 h for heating and 0.5 h for loading the raw material, for discharging the waste material and for cleaning the apparatus. A distillery unit can complete 3, 4 and 8 operation cycles, if the operation time of this unit is 9 h, 12 h and 24 h, respectively. The mass of processed flowers for 24 hour is 9.6 t and 10.6 t, respectively in the installations 1 and 2. The produced rose oil will be 2.7 kg and 3.0 kg, respectively, if the assumed oil yield is 3.5 t flowers per 1 kg oil.

Steam consumption. The hourly consumption in 5.5 m^3 distiller is 720 kg/h or an equivalent heat flow of 409.5 kW. The consumption for an operation cycle is 1800 kg as the duration of steam supply is 2.5 h. The maximal round-the-clock consumption in two distillation units completed 8 operation cycles is 28.8 t equivalents to 58.96 GJ heat quantity. The hourly steam consumption of 3 m^3 distiller is 400 kg/h (227.5 kW) and for a cycle - 1000 kg steam. The maximal round-the-clock consumption in four distillery units completed 8 operation cycles is 32 t steam (65.5 GJ). The hourly steam consumption in cohobation unit is 390 kg/h (221.8 kW). The maximal consumption during 24 hour operating is 9.36 t (19.2 GJ). The total maximal steam consumptions in the installations 1 and 2 are 1830 kg/h (1041 kW) and 1990 kg/h (1132 kW), respectively. The total round-the-clock steam consumption are 38.16 t (78.1 GJ) and 41.36 t (84.7 GJ), respectively for these two installations. The steam consumption in the cohobation unit represents 24.5 % and 22.6 % of the total steam consumption in these installations, respectively. In case of 12-hour operation, the steam consumptions are 19.08 t (39.1 GJ) and 20.68 t (42.3 GJ), respectively in the installations 1 and 2. For a 20-day campaign and an average of 12-hour workday, the total steam consumption will be 381.6 t (781.2 GJ or 217 MW.h) and 413.6 t (846.8 GJ or 235 MW.h), respectively for these installations.

Fuel consumption. The steam boiler KPN 2000/8 of "Promishlena energetika" PLC, Varna was selected as its steam production is closer and higher than the maximal steam consumption in the installations. The steam production of this boiler is up to 2000 kg/h at 8 bar pressure. Its rated heat capacity is 1415 kW, if the temperature of supplying water is 50°C. The technical specification of this boiler points a consumption of up to 135 kg/h fuel oil or up to 171 nm^3/h natural gas. In Table 2 the consumptions of fossil fuels (fuel oil, LPG, PNG, CNG) and biofuels (wood pellets, wood chips) are presented. They are related to a boiler generating 48 t steam at 24-hour operation. The specific fuel consumption is related to 1 t saturated steam at 8 bar pressure. If the steam production can be smoothly adjusted, then the fuel consumption could be reduced up to 20 %. This reduction is 20.5 % and 13.8 % in the installations 1 and 2 used 38.16 t and 41.36 t steam per day, respectively.

Table 2. Fuel consumptions of steam boiler generating 48000 kg steam at 24-hour operation basis

Fuel	Specific consump-tion, kg/t	Hourly consump-tion, kg/h	Daily consump-tion, kg/d
Fuel oil	67.5	135.0	3240
LPG	61.4	122.8	2947
PNG gas	57.1	114.3	2742
CNG gas	57.1	114.3	2742
Wood pellets	199.8	399.5	9589
Wood chips	339.6	679.2	16301

For above mentioned fuels, their prices per 1 kg fuel, the cost of heat released in their combustion in the boiler and the daily cost of fuels used are presented in Table 3. The last costs are compared with the cost of fuel oil used traditionally. When the natural gas (PNG, CNG) is used as fuel, the daily cost is a half. In case of usage of wood pellets and chips, these costs are three and five times lower, respectively.

Table 3. Costed fuel and energy consumptions of a steam boiler generating 48000 kg steam at 24-hour operation basis

Energy source	Price, BGL/kg EUR/kg	Cost of heat, BGL/GJ EUR/GJ	Daily cost, BGL/d EUR/d	Compa-rison, %
Electric energy	-	68.24 34.89	9270 4740	105.6
Fuel oil	2.71 1.38	64.66 33.06	8780 4489	**100.0**
LPG	1.94 0.99	42.08 21.51	5716 2922	65.1
PNG	1.49 0.76	29.80 15.24	4085 2089	46.5
CNG	1.45 0.74	29.00 14.83	3976 2033	45.3
Wood pellets	0.30 0.15	17.65 9.02	2877 1471	32.8
Wood chips	0.10 0.05	10.00 5.11	1630 833	18.6

Consumption of cooling water. It is 5.58 m^3/h (389.7 kW) or 3.04 m^3/h (212.5 kW), respectively in the distillation units 1 and 2. This consumption in the cohobation unit is 0.38 m^3/h (95.5 kW). The corresponding rejected heat flows are pointed in brackets. The total round-the-clock water consumptions are 187.7 m^3 (31.4 GJ) and 203.7 m^3 (34.1 GJ), respectively from the installations 1 and 2. The heat quantities, brought out with cooling water, were given in brackets. These heat quantities brought out represent 40.2% from the corresponding heat quantities incoming with supplying steam.

Consumption of tap water. This type of water is mainly used for flooding rose flowers in the distillation vessels; for diluting the distillate waters (floral water) before their cohobation and for steam generation.

Water for flooding. The ratio between the flooding water and rose flowers in distillation apparatus is 4 to 5. For an operation cycle, 1.6 m^3 fresh tap water is used in 5.5 m^3 distiller and 0.9 m^3 water in 3 m^3 distiller. The rest of the flooding water is boiling water exhausting from cohobation apparatus. The round-the-clock tap water consumption is 25.6 m^3 and 28.8 m^3, respectively in the installations 1 and 2.

Water for diluting. The ration between the distil-late waters and tap water is 2:1. To the total quantity of 26 m^3 primary and secondary distil-late waters should be added 13 m^3 fresh tap water in the installation 1 for 24 hour operation. In the installation 2, 13.8 m^3 tab water should be added to 27.6 m^3 distillate waters of the both types.

Water for steam generation. For the selected boiler with a capacity of 2 t/h steam, 2 m^3/h fresh tap water should be supplied after an appropriate demineralization.

Resuming the total round-the-clock consumption of tap water is 40.6 m^3 and 44.6 m^3, respectively in the installations 1 and 2.

Consumption of electric energy

For cooling tower. The exhausted cooling waters are 187.7 m^3 and 203.7 m^3, respectively for the installations 1 and 2 for 24 hours. The heat flows of 365 kW and 395 kW should be removed respectively from these hot waters in the installations 1 and 2. The average necessary electrical power of cooling tower will be 3.1 kW and 3.36 kW, respectively for two installations at the assumed specific consumption of 0.0085 kW/kW.

Hence, round-the-clock consumption will be 267.8 MJ и 290.3 MJ, respectively for two installations.

For pumping and supplying cooling water. This electrical consumption is 122.7 MJ and 133.2 MJ, respectively in the installations 1 and 2 for 24 hours.

For other processing and services. The total maximal consumption of electric energy for supplying and circulation of different types of waters, for steam boiler and for the separation of water from the flowers wasted was evaluated to 7 kW. The maximal consumption during 24 hours for above pointed processing purposes will be 604.8 MJ.

Therefore, the total round-the-clock consumption of electric energy will be up to 1028 MJ.

Specific consumptions. The specific steam consumptions are 3.97 kg/kg (8.13 MJ/kg) and 3.90 kg/kg (7.84 MJ/kg) steam per 1 kg flowers, processed for 24 hours, respectively in the installations 1 and 2. The specific steam consumptions for manufacturing 1 kg rose oil are 14.1 t (28.9 GJ/kg) and 13.8 t (28.2 GJ/kg), respectively for two installations. In the brackets, the corresponding specific heat consumptions were pointed. The specific fuel consumptions for processing 1 kg flowers during round-the-clock operation are up to: 0.26 kg/kg for natural gas (PNG, CNG), 0.28 kg/kg for LPG, 0.31 kg/kg for fuel oil, 0.90 kg/kg for wood pellets and 1.54 kg/kg for wood chips. The specific fuel consumptions for deriving 1 kg rose oil during round-the-clock operation of the installation 2 are respectively: 914 kg/kg in case of using natural gas (PNG, CNG), 982 kg/kg for LPG, 1080 kg/kg for fuel oil, 3196 kg/kg for wood pellets and 16301 kg/kg for wood chips, respectively. The specific consumption of cooling water is up to 10.2 L per 1 kg flowers. The specific consumption of tap water is up to 4.2 L per 1 kg flowers. The specific consumption of electric energy in cooling tower reaches to 27.9 kJ per 1 kg flowers and for pumping cooling water – up to 12.8 kJ/kg. The total specific consumption of electric energy will be up to 107.1 kJ/kg (30 W.h/kg).

The costed shares of the expenses for fuels, electric energy and tap water. The shares for different fuels related to 24-hour operation of the installation 2 were evaluated as follows: 21.4 % in case of using fuel oil, 13.9 % for LPG; 9.9 % for PNG; 9.7 % for CNG; 7 % for wood pellets and 4 % for wood chips. This share increases to 22.6 %, if electric energy is used for steam production. The share of electrical energy used in the installation 2 (excluding steam production) is 0.17 %. The costed share of tap water used is up to 0.32 %.

Discussion

Commentary about the work schedule of distillery and its energy efficiency. The above-mentioned results relate to 24-hour operation of distillery. In this case the distillery is loaded to the maximum and the specific consumptions of energy sources are lower and its energetic efficiency is the highest. Blooming rose flowers and their picking determine the work schedule of distillery. In practice, the distillery works at 24-hour work schedule only 20-25% of campaign period. The distillery operates in one-shift mode at the beginning and the end of the campaign as these periods are a quarter of the work period. In the rest of the campaign, this manufactory works in two-shift mode. In these periods of time, the apparatuses and the circulating water flows should be heated additionally for the first batch for the day; the heat recuperation will be not sufficient; the steam boiler could not work in continuous mode.

Commentary about the deal of expenses for energy sources. Most significant is the cost share for fuel consumption as it is over 20% in case of using fuel oil. This share could be reduced to 4 %, if wood chips are used as fuel. According to the Report of European commission (2019), the energy share of production cost in energy intensive manufacturing sectors is in the range from 3% to 20 %. Therefore, the production of rose oil is also in these sectors. In the conclusion of above report the following directions for expected development in these energy-intensive productions were pointed: increasing energy efficiency, reducing specific energy costs and reducing fossil fuel consumption. This development should also be achieved through the usage of certain EU instruments for encouraging industrial businesses to develop and implement new energy-saving processes.

Comparing the specific energy consumption for producing rose oil and other products. In the section "Results" it was specified that the average specific heat consumption is 8 MJ/kg for processed flowers and 28 GJ/kg for manufactured rose oil. If these values compare with the specific energy consumptions listed in the section "Introduction", the following ascertainment can be done: The specific heat consumption for processing 1 kg rose flowers is comparable to the specific energy consumptions for manufacturing agricultural and food products. On the other hand the specific heat consumption for obtaining 1 kg rose oil is extremely high. It is higher in several decimal orders than the specific energy consumptions for producing agricultural, food, chemical and metal products. This energy consumption is only comparative to the primary gold production. This high energy consumption can be explained by two circumstances: First, the concentration of target sub-stance in the raw material is very low. The oil content in rose flowers is 285 ppm (0.028%), while the gold in ore is 1-5 ppm. The oil concentration in rose flowers is considered as a botanical feature. Although, there are Rosa damascene varieties reported with higher oil contents: from 0.032 to 0.049% (Kovatcheva et al. 2011). Second, the traditional technology for producing rose oil applies triple heating of water (first to 170°C for steam generation and after this to 100°C: for distillation and cohobation) and following vaporization.

Possibilities and alternatives for improving energy efficiency. These approaches can be divided in two groups: (I) Approaches applying known and approbated engineering solutions and design variants; (II) Research and development of novel technical solutions. The following variants can be assigned for the first group: (i) changing fuels for steam production: from fossil fuels toward biofuels; (ii) applying flow diagrams that allow additional heat recovery in the installation. To the second group may be referred (i) using distillation assisted by ultrasonic treatment for shortening process duration and following a reduction of heat consumption; (ii) applying low-temperature membrane processes (as reverse osmosis and pervaporation) for processing distillate water as an alternative of high-temperature cohobation. These variants will be discussed and analysed in-and-out in a subsequent study.

Conclusions

The specified expenses of energy sources for the production of rose oil according to the traditional technology show that the highest expenses are for the fuel and for steam generation, respectively. The specific heat consumption for the production of 1 kg rose oil reaches to 28 GJ/kg and it is only smaller than the specific energy consumption for the primary extraction of gold. In case of using fossil fuels, their costed shares in the final product vary from 10% (for natural gas) to 21% (for fuel oil). When biofuels are used this share can be reduced to 4% (for wood chips). The costed share of used tap water is 0.32% and for electric energy – 0.17%.

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