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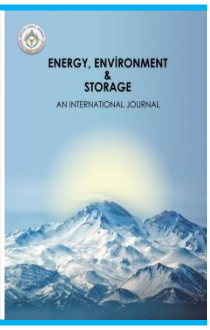

Evaluation of Tea Factory Wastes in Energy and Other Areas - A Review

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ABSTRACT. Today, orientation towards alternative energy sources has gained great importance. Biomass resources are easily available, plentiful, inexpensive, environmentally friendly and sustainable renewable energy sources. Biomass resources have the potential to be used not only for energy production but also in many different fields. One of the sources of biomass is the tea factory wastes (TFW) released during black tea production. This resource, which has no economic value, can be used in many different fields and forms. In this study, these studies made with tea factory wastes were compiled and gathered under five main headings. These are agriculture and animal husbandry, building materials, environment, energy and chemistry. It is thought that examining the studies in this way will be a guide to fill the existing gaps in the literature and lead to development.

Keywords: *Tea factory waste, agriculture and livestock, energy, environment*

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1. INTRODUCTION

Traditional fossil fuels, which are used more than renewable energy sources in the world, are non-renewable resources with the potential to be depleted. In addition, it is known that non-renewable resources cause great harm to human health and the environment, such as global warming, climate change and harmful emissions[1]. Renewable energy sources promise a more liveable future and hope by minimizing these damages. One of the renewable energy sources with a very high potential is biomass energy. Biomass energy is a controllable energy that does not have interruption problems as in solar and wind energies[2].Biomass resources have the potential to be used in many different areas because they are clean, sustainable, diverse, easily available and inexpensive. Biomass consists of terrestrial, aquatic, domestic and industrial wastes. Energy from biomass sources is widely utilized as a heat source in industries such as forestry and paper industries, and for cooking and heating. In addition, biofuels obtained from biomass can be used in areas such as transportation and electricity generation. Besides its use as energy, biomass can also be utilized to obtain various high value-added chemicals[3, 4]. Figure 1 shows the conversion of biomass wastes into biochar and its use in various fields.

Figure 1. Converting organic waste into biochar and used in different areas (adapted from [5])

One of the sources of biomass is tea waste, which is formed from the fiber, stem and powder parts of tea leaves, which are released during the production of black tea in tea factories. The tea beverage is obtained by processing the leaves of the Camellia Sinensis plant. Black tea is consumed the most in the world. This is followed by green tea, oolong tea and white tea, respectively [6].White tea from unripe tea leaves, green tea without fermentation, oolong tea by semi-fermented and black tea by full fermentation is produced [7]. In our world, where two-thirds of the population consumes tea, tea consumption increased by 4.5 percent from 2007 to 2016, reaching approximately 5.5 million tons (Fig. 2) [8].

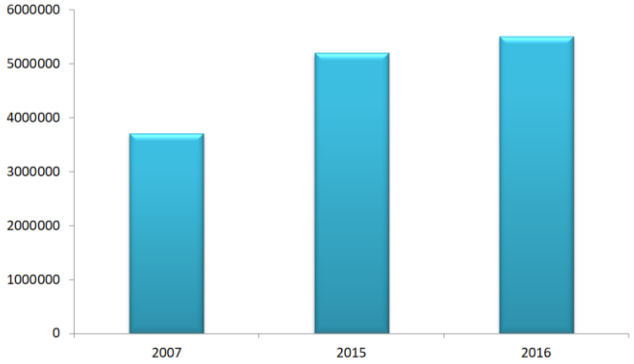

Figure 2. World tea consumption quantities

The tea plant, which is consumed intensively, grows in certain regions due to climate selectivity and it is desired that the factories be close to the raw material. This ensures that tea factory wastes are collectively formed at certain points and facilitates accessibility. In addition, the transportation of TFW does not involve great difficulties and facilities for its evaluation can be established at any point. Another factor that makes TFW worth using is that it occurs spontaneously in tea production processes and has no economic value.

Tea production consists of 5 main processes. These are withering, rolling, fermentation, drying and sorting packaging. Withering is a process for lowering the moisture content of tea leaves. The process of spreading the cell sap to the surface by curling the leaves in the rolling machines takes place in the rolling unit. Then, the fermentation process is started in the presence of moist hot steam in the fermentation unit. When the tea has the desired taste, smell and color, it is dried in the ovens in the drying unit. Finally, the tea is separated from the unwanted fiber, stem and powder parts in its content with various steps and categorized and packed in big bags[9]. Figure 3 shows the process of separating fibers from tea. In Figure 4, there is an image of the tea factory wastes.

Figure 3. Fiber receiving system

Figure 4. Tea factory waste

The content of tea and tea waste varies depending on factors such as the region where it is grown, the harvest period and the production method. In a study, two different production methods are discussed and mineral substance values are examined according to different parameters. The effect of production methods on the amount of mineral matter is shown in Figure 5 [10]. In general, TFW has a high C content of around 50% and an O content of 41%. It also contains H, N and S elements. TFW is a lignocellulosic biomass source containing lignin, cellulose and hemicellulose together [11]. TFW is rich in C, Cl, N and K however poor in P. Tea waste has a C/N ratio of 26 and a pH of 5.3 [12].

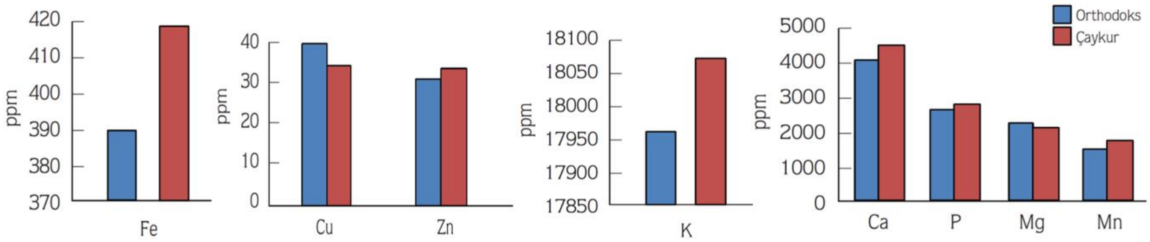

Figure 6. Tea content change according to the production methods (adapted from [10])

Each element in its content creates a potential for the utilization of tea factory wastes in different areas. In this study, the areas where tea factory wastes, which are a biomass source, are used were compiled and grouped under 5 main headings. These are agriculture and livestock, environment, energy, building materials and chemistry.In this way, it has been presented to the attention of researchers with examples in which areas and in what ways the wastes of the tea factory are used. It is aimed that this study will shed light on filling the gaps in the literature and generating new ideas.

2. AGRICULTURE AND LIVESTOCK

Chemical fertilizers have been used for many years to meet the nutritional needs of cultivated plants. However, excessive and unilateral use of these fertilizers causes some environmental problems. For this reason, it has become necessary to use organic fertilizers more effectively in agriculture[13]. In traditional agricultural systems, the decrease in the amount of organic matter in the soil causes two important problems as the sustainability of the soil and the decrease in production efficiency. In the case of insufficient organic matter coverage, the development of plants grown in agricultural lands and the activity of living creatures using the soil as a habitat are significantly limited. Along with the protection of soil fertility, sustainability is largely possible by adding sufficient amount of organic material to the soil [14]. Barnyard manure is the most important and most used organic waste material source. However, recent studies have shown that many vegetable waste can also be a good source of organic matter [15].

Re-utilization of lignocellulosic wastes in various areas will increase the efficiency of the relevant enterprises and prevent environmental pollution caused by these residues. It is rich in polymeric structures carbohydrates such as cellulose, hemicellulose and lignin. Biotechnological applications offer unique options for the preservation of natural balance in the evaluation of waste. It is possible to combine lignocellulosicwastes with various methods and evaluate them as organic fertilizers in agricultural areas and forest nurseries [16]. The benefits of tea waste to the soil come from some of the elements in it.

One ton of the tea waste contains on average 25 kg pure nitrogen, 3 kg phosphorus and 40 kg potassium. The nitrogenous organic substance in the soil is broken down by microorganisms and turned into a useful form for plants. Phosphorus for plants; It is an important nutrient element for root development, maturation of the plant and increasing resistance against diseases. The rate of potassium in the soil affects the structure of the soil, organic matter, lime and pH.

The tea compost;

- It increases the water holding capacity of the soil.
- It increases the amount of nutrients in the soil.
- Regulates the relationship between plant nutrients in the soil.
- It increases the temperature of the soil.
- It increases soil organisms and microbiological activity.
- It provides aeration of soil.
- It reduces the dependence of soil on chemical fertilizers [17].

In a study carried out, tea waste from tea factories was mixed with fresh goat manure, dry clover and water. According to the data obtained, it was concluded that tea litter compost can be formed in a short time and used in agriculture. It is seen that this compost is especially important in terms of turning the nutrients in the tea into the tea plant [18]. Table 1 shows the studies using three different mushroom species. The general opinion is that tea wastes can be used in this area.

Table 1. Effect of TFW on mushroom species yield

Mushroom Plant	Result	References
Pleurotus eryngii (DC. ex Fr.) Quel.	It was concluded that the tea waste can be used in P. eryngii cultivation.	[19]
Agaricus bisporus (L.) Sing	When tea waste is evaluated in mushroom cultivation, it is possible to obtain both a product rich in protein and the use of waste compost as fertilizer.	[20]
Ganoderma lucidum	It was observed that the effect of substrates prepared with oak sawdust and tea production wastes on mushroom yield was positive.	[21]

The positive effects of tea waste compost on the development of green onion, pepper (capsicum annuum), spinach (Spinaciaoleracea L.), lettuce (Lactucasativa L.), fenugreek (TrigonellaFoenumGraecum), corn (Zea mays L.) and begonia (Begonia eliator 'Toran') plants root, leaf, wet and dry weights, fruit weight, plant height, nitrogen (N) and potassium (K) contents have been identified. Figure 7 shows the effect of 0 to 8% tea waste compost on pepper plant growth. It was determined that the growth of the plant accelerated as the dosage of the mixture compost obtained from TFW increased[22-27].

Figure 7. The effect of the same amount of salt dosage and increasing level of tea litter compost applications on the plant height of pepper (adapted from [22])

Since there are some harmful factors for animals in tea waste, it has been determined that these wastes should be used in animal nutrition in a limited way. There is about 6.3% tannic acid in tea wastes that prevents protein metabolism. Therefore, it is not possible to use it as animal feed. However, a method has been developed: After tea wastes are left in chlorine-free water diluted 1/50 at night, the product obtained is purified from tannic acid without any change in the protein content. So this product can be made available as chicken feed [12]. The effects of tea wastes used instead of oat crop as roughage on live weight gain, roughage consumption, digestion degree of total ration dry matter and wool quality were investigated. As a result, tea wastes with a crude protein content of around 12-14% should be used in animal feeding in a limited manner [28].

When the studies were evaluated, it was determined that good yield was obtained as a result of the use of tea factory wastes as a mixture material in agriculture, however its use as a nutrient in animal husbandry was not very efficient. On the other hand, it is possible to evaluatesuccessfully the content of TFW in these areas by making it more useful.

3. BUILDING MATERIALS

Governments are setting new protective standards in the construction industry as human and environmental health awareness comes to the forefront with increasing demand on the community side. Therefore, natural resources are studied for important alternative materials to synthetic based and harmful dyes. One of these sources is tea waste. Tea waste can be used as coloring material. Besides the advantages of the wood material used in construction, it has to be treated with some preservatives and colorants in order to be protected against external influences and to be aesthetic[29]. Tea wastes can be applied for the purpose of obtaining and developing natural and water-based wood preservatives (dyes) and colorants that are harmless to the environment and human health by obtaining extracts from the natural product of tea [30].

It is possible to use tea wastes in different structures in the construction area. One of these is briquette production from tea waste. Cold-hardened composite briquette, which is the first stage of the process of producing iron metal from iron-based ore and wastes by blending with tea waste, was produced. The best results were obtained by drying the briquettes produced by adding CMC (Sodium carboxymethyl cellulose) up to 3% of the total material for 120 minutes at 200ºC [31]. In another study, the use of treated waste tea ash instead of cement in pavement blocks at 10%, 20%, 30%, 40% and 60% dosages was investigated. Replacing the cement with waste tea ash has reduced the quality of the paving blocks. However, it has met the minimum requirements set for some areas of use. The replacement of waste tea ash to cement has led to the production of a more sustainable and cost-effective paving block (Fig.9).This study is noteworthy as it is aimed at evaluating the secondary waste generated by the incineration of TFW. In this case, two-fold gain is obtained. TFW can be evaluated in two different areas and new waste generation is prevented. In another study, the usability of tea wastes as a natural fiber in concrete was investigated. As a result, it was concluded that tea waste can be used as natural fiber up to 7 kg in 1 m^3 of concrete, however it would be appropriate to use up to 5 kg in places that will be exposed to abrasion[32, 33].

Figure 8. Processed waste tea ash and fresh blocks (adapted from [32])

The usage potential of tea wastes in paper production, which is another building material apart from the construction sector, has been examined. It has been concluded that if the tea factory wastes are used in pulp production, it will contribute significantly to the raw material supply problem [34].In another study, it is concluded that tea wastes have taken place in the production of composite plates by determining some properties of particle board produced using tea waste by experimental methods and modelling of the results with fuzzy logic method was investigated. In addition, it has been tested efficiently in line with the analyses applied on the plates produced[35]. Figure 9shows the example of particle plate produced using tea waste and red pine.

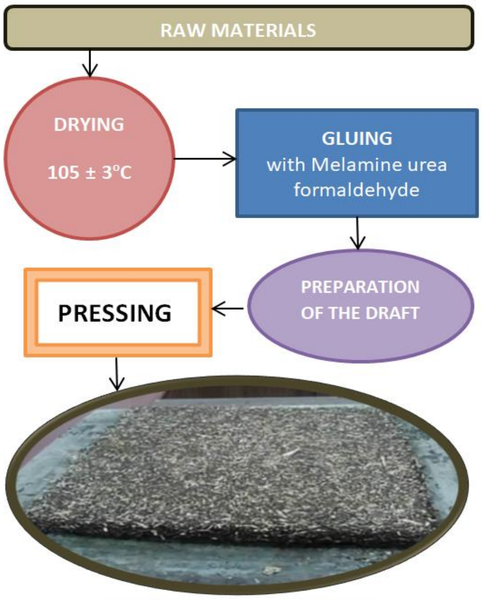

Figure 9. Hot pressed plate draft (adapted from [36])

In the use of TFW in the field of building materials, examples of paint, briquette, concrete, paper and particle board are encountered. In addition, it is seen that ash, which is the secondary waste formed after TFW is burned to obtain energy, can also be evaluated.

4. ENVIRONMENT

Although there are many methods such as evaporation, chemical precipitation and oxidation in wastewater treatment, one of the most used applications is adsorption. Adsorption is the process of passing the contaminant from the liquid product to the solid adsorbent [37].Large amounts of water are used in industry. Industrial wastewater contains pollutants that are harmful to the environment and health, such as toxic substances, heavy metals and inorganic substances. Cleaning of industrial wastewater is essential both from an environmental and economic point of view. In addition, the increase in the world sea trade volume with each passing year has led to the increase in the dimensions of the tanker accidents that may occur in oil transportation, and thus the pollution dimensions. The magnitude of environmental impact caused by oil pollution caused by a tanker accident, the difficulty of cleaning activities and the high cost are clearly seen from past accidents [38, 39]. The use of organic biomass sources in wastewater treatment helps reduce carbon emissions and contributes to reducing the cost of wastewater treatment [40].

Activated carbons (AC) are adsorbents with high surface area and porous structure with high performance adsorption potential. In recent years, the production of activated carbon using biomass resources has become widespread due to its cheapness and effectiveness. TFW lignin can be used in the production of activated carbon due to its cellulose and hemicellulose properties as well as its high carbon content. As a result, it was determined that activated carbon produced with KOH (potassium hydroxide) showed higher performance in Methylene Blue adsorption, activated carbon produced with $ZnCl_2$(zinc chloride) in phenol adsorption and activated carbon produced with H_2SO_4(sulfuric acid) in adsorption of metals [41]. Figure 10 shows an activated carbon production reactor.

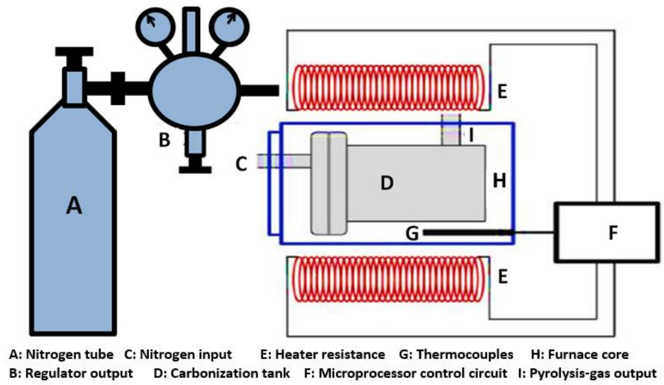

Figure 10. AC production reactor (adapted from [42])

In another study, activated carbon was produced from a mixture of tea waste-H_3PO_4(phosphoric acid) with an activation method including microwave pretreatment and carbonization. Methylene blue and phenol adsorption were investigated to determine the adsorption capacity of activated carbon produced from tea waste under optimal process conditions. Due to the high surface area and mesopore content of tea waste, it has been determined that it can be used as an adsorbent in the removal of organic substances that cause pollution in water [43]. Figure 11 shows the stages of preparing activated carbon with microwave pretreatment and impregnation using H_3PO_4 and K_2CO_3 (potassium carbonate).

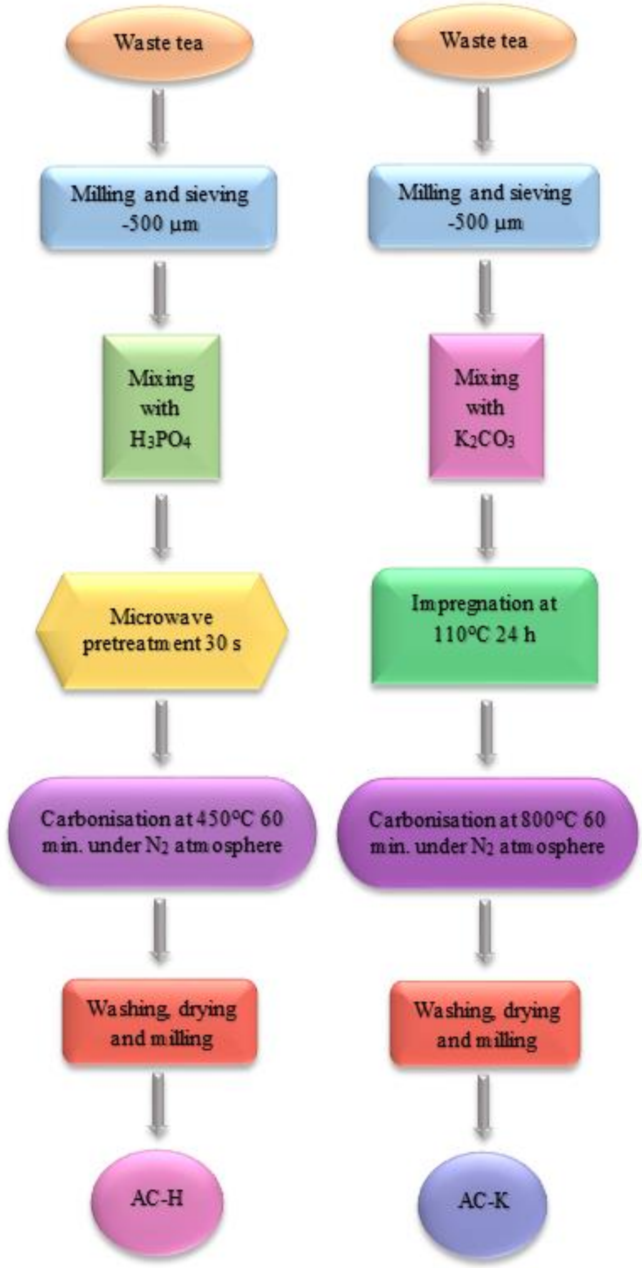

Figure 11. The schematic illustration of the production processes of the activated carbon samples (adapted from [44])

In another study, tea factory wastes were used as biosorbent material for the removal of Pb(II) from synthetic wastewater. The maximum Pb(II) removal capacity of TFW was found to be 22,111 mg g^{-1} at 200 mg L^{-1}[45].Biochar is a substance that can be used for various purposes. In a study, biochar was prepared from TFW with five different carbonization methods and the prepared biochar was used for the adsorption of tetracycline from the water medium. It has been observed that carbonization methods have different effects on the properties of biochar. It has been determined that $KHCO_3$ (potassium bicarbonate)-biochar has the maximum adsorption capacity[46].In another study, TFW biosorbent was used for Cu (II) and Zn (II) adsorption. Zinc showed higher adsorption efficiency compared to copper[47].

AC and biocharproduction with different materials and methods to be used in wastewater treatment from a cheap and environmentally friendly biomass source such as TFW shows very efficient results.

5. ENERGY

Energy sources used in the world are generally grouped in two main groups. These are non-renewable or conventional energy sources are also known as fossil fuels (oil, coal and natural gas) and renewable energy sources (solar energy, biomass energy, geothermal energy, wind energy, wave energy, hydrogen energy, etc.). The ever-increasing world population also increases the demand for energy. As a result, concern that the limited resources of fossil fuels will quickly decrease and be exhausted and toxic and poor quality wastes from high quality energy need cause major environmental problems forced scientists to conduct research on new energy sources [48]. In this regard, biomass resources are a very good alternative because they provide continuity and are a cheap and environmentally friendly renewable resource.

In a study, biochar was derived from tea factory waste and grape seed resulting from the processing of tea and grapes, and the usability of the obtained biochar as a solid acidic catalyst in the production of biodiesel from waste cooking oil was investigated. As a result, it has been determined that it is functional to convert tea wastes and grape seeds into carbon catalysts with high added value instead of inefficient burning or leaving them to decompose in nature[49].Such studies show that versatile and functional products that can be used not only for a single purpose but also in different fields can be produced from TFW.In Figure 12, an example of biochar production by pyrolysis from tea waste and the use of biochar in energy storage is shown schematically.

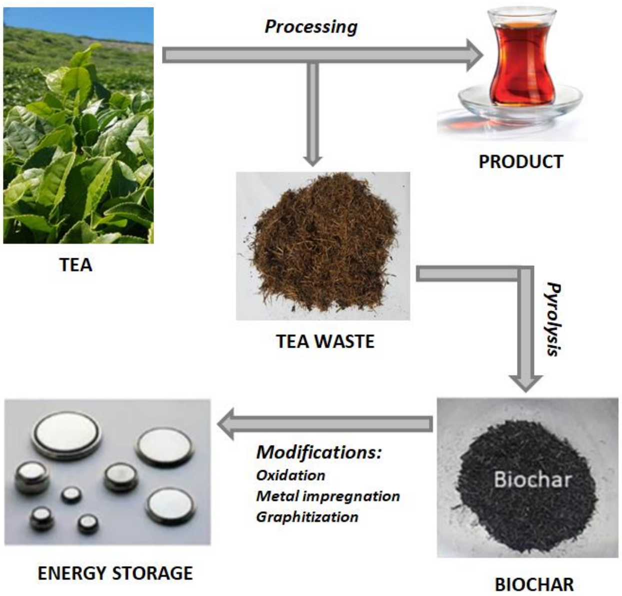

Figure 12. Use of tea waste biochar for energy storage (adapted from [50])

Another form of TFW that can be used in energy storage is its use as electrode material in supercapacitor design. In a study, a hybrid electrode consisting of TFW-based activated carbon and graphene was produced. The capacitance of the hybrid electrode, which was subjected to various processes to increase the electrochemical performance, was measured as 110 F/g[51].In another study, the catalyst produced from TFW using NaOH was used both as an electrode material in supercapacitor design and as a catalyst in hydrogen production experiments. The results were found promising. In this study, TFW appears to be quite functional[52].

During active carbon production from tea waste, it can be obtained in other chemical products. For example, tea waste can be subjected to pyrolysis. Pyrolysis is the oldest and simplest method to obtain gas from biomass, and it is the thermal decomposition process that occurs by heating organic materials in an oxygen-free environment. As a result of pyrolysis, substances such as gases, tar, organic compounds, water and charcoal are obtained[53].

In another study, three different biomass sources, including tea waste, were subjected to pyrolysis with and without catalyst, and the yield of liquid product was investigated. It was observed that the structural properties of the biomass and the catalyst used affect the liquid product yield [54]. It is also possible to obtain gaseous energy from TFW. In a study on this subject, gasification reactions of tea waste were carried out in an upstream tubular reactor in air and air+steam medium in order to produce a hydrogen-rich gas mixture. The activities of the catalysts were investigated in the gasification reactions of tea waste. It was observed that the liquid products obtained were rich in phenolic compounds and caffeine, and there was not much change in the structure of the solid products [55].

An example of solid energy production from tea factory waste is pellets. According to the data obtained as a result of pellet biofuel production from TFW, it has been determined that the use of tea waste as pellets is suitable both in terms of fuel properties and environmental factors [56]. In another study, it was observed that the materials were pelleted with high quality without using any adhesive and the tea pellets were in a solid structure as a result of physical tests [57].

Bioenergy and biofuel in solid, liquid and gas form can be obtained from tea factory wastes. These are valuable products with a wide range of uses. However, studies on the use of TFW in the field of energy can be increased.

6. CHEMISTRY

Tea leaf is a rich resource of polyphenols, especially catechins. Depending on the region where it is grown, the amount of catechin in green tea can reach up to 30% of the dry weight of the leaf. Catechins are of interest because they are very beneficial for human health. The catechin found in tea is also useful for the food industry [58].Tea factory wastes also contain caffeine and catechin, and it is possible to obtain them by different methods. Caffeine production from tea waste consists of three main processes. The first of these is to expose tea wastes to solid-liquid extraction with hot water. The aqueous extract obtained here is subjected to liquid extraction in the second stage with a solvent that can dissolve caffeine well, such as chloroform. The final stage consists of solvent recovery and classification of raw caffeine [59].

In a study, caffeine and catechin amounts, extraction and analysis methods of wet tea, caffeine powder and black tea waste were investigated. Wet tea samples were found to contain higher amounts of catechin than waste, in accordance with the literature, however black tea waste and caffeine powder also contained significant amounts of catechin. It was determined that the most efficient method was hot water extraction[60]. In another study, the extraction of caffeine and catechin from the same samples by microwave method was investigated. In the samplings conducted in 2013-2014, it was determined that the samples showed significant differences according to the years without a standard catechin and caffeine content and the seasonal conditions [61]. In a study in which caffeine was extracted from tea waste by the supercritical carbon dioxide extraction method, it was concluded that it would be possible to obtain approximately 5 times the caffeine need of Turkey when a process that can produce caffeine by only evaluating TFW is established [62]. The flow chart of the supercritical extraction setup is shown in Figure 13.

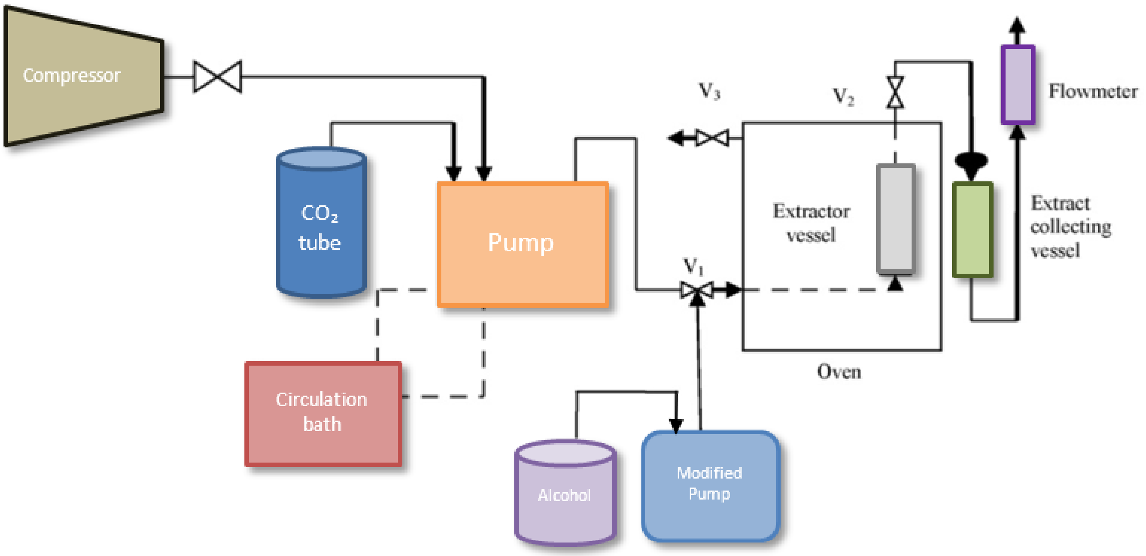

Figure 13. Flow diagram of the supercritical extraction set-up (adapted from [63])

One of the most important areas of study recently has been on antioxidants, which play a role in cleaning free radicals that cause many diseases such as cancer, atherosclerosis, cataracts, Parkinson's disease and aging. Antioxidants are defined as molecules that delay, clean or prevent the oxidation of their molecules against oxidative damage. Antioxidant mechanisms are present in the organism as protective against pro-oxidant substances. These remove harmful oxidants or repair damage caused by the reactive oxygen species in vivo [64]. Studies on the antioxidant efficiency of tea wastes have been conducted. Phenolic components of tea and its wastes were examined and the effects of tea samples on enzymatic activity were measured by measuring antioxidant enzyme activity in the erythrocyte cell model. As a result, it has been determined that tea and wastes have antioxidant capacity and also green tea and its leaf waste have higher antioxidant effect than black tea [65].

Another study aimed to determine the phenolic content of extracts from black and green tea and their different wastes and to compare their protective effects against oxidative DNA damage induced by hydrogen peroxide in human lymphocytes by single cell gel electrophoresis (comet) method. As a result, it has been determined that tea wastes are as effective as tea itself and can make an economic contribution by evaluating it in terms of its protection against DNA damage [66].In another different study, it was aimed to develop a new method to increase the extract rate of Turkish tea. Optimum conditions were determined to obtain suitable extract from tea waste. As a result of the processes, the extract rate of the tea was increased from approximately 29% to 32% and no negativity was found in the tasting tests[67].

It is seen that tea factory wastes are evaluated in different ways in the field of chemistry. The work appears to be promising, at the same time open to enrichment.

7. CONCLUSION

The world is in search of resources to meet the needs of the increasing population. In this case, it is wise to make wastes that have no economic value available. In this study, the evaluation methods of tea factory wastes, which are released in large quantities and collectively, in different areas were investigated.Studies are grouped under five headings: agriculture and animal husbandry, building materials, environment, energy and chemistry[68].The aim of the study is to show that a biomass resource can be used in different ways and to give new ideas to researchers.The results of the study are listed below.

It is seen that tea factory wastes are used in the development of different types of plants such as pepper, spinach, fenugreek, mushroom species, lettuce in agriculture. It has been determined that TFW can be used as a compost material thanks to the nutrients it contains. The effect of TFW can be observed by diversifying plant species. Then, the efficiency can be increased by using it in greenhouses and it contributes to the economy.

It has been determined that TFW should be used in a limited way in animal husbandry. However, a method such as soaking in 1/50 diluted chlorine-free water has been developed and the harmful substance for animals has been removed [12]. Such new methods can be developed. Its effects on the development of animals and its use in farms can be investigated.

In the field of TFW building material, it has been used to make paint, briquettes, paving stones, concrete, paper and particle board. In some studies, it has been determined that it has sufficient performance and in others it is at a level that can be improved. The use of products such as newspapers, packaging, ornaments and insulation materials can also be investigated. Since no new waste will be generated in its use as a building material, the damage to the environment is reduced to zero.

It has been used as a biosorbent in the production of multifunctional products such as TFW activated carbon, biochar and in the treatment of wastewater.

The works have been enriched by using different materials and methods. It is seen that TFW can be used successfully in this field. It is seen that different efficiencies are obtained for different pollutants. Comparisons can be made by diversifying the studies.

TFW has been used in the energy field in the production of solid, liquid and gas biofuels and energy storage. These are biodiesel, biochar, hydrogen, pellet production and supercapacitor design. It is promising that TFW can be evaluated in this way in various forms. However, energy is a very broad field and is open to development.

In the field of chemistry, TFW has been used in the production of caffeine and catechin by different methods and in the production of antioxidants that play a role in curing various diseases. There are also different studies where it is evaluated as a protective against DNA damage and as an extract enhancer. The fact that a waste material with no economic value can be made useful in different ways will shed light on new studies.

As can be seen, tea factory waste, which is a biomass source, can be used in different areas thanks to its rich content. Studies in these areas can be diversified, and the use of TFW in different areas such as food, clothing, etc. can be investigated. In addition, studies can be developed by using different materials and methods in studies with insufficient efficiency.

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