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Review IJCEP

Tall Oil: Production, Applications, Global Market, and Future Prospects- A Review

Sandeep Rai[1]

Abstract

The global energy demand is experiencing rapid growth due to overpopulation and massive industrialization worldwide. The stringent environmental regulations to minimize fossil fuel reliance have led to a global need to develop renewable and sustainable fuel sources. Hence, industries are increasingly looking towards non-edible oils as natural resources for biofuels, and one such promising feedstock is tall oil, a valuable by-product of the pulping industry obtained through the Kraft process. This review provides an overview of tall oil production from woody biomass, the methods of tall oil purification, and the treatment of refined tall oil for the development of value-added products, bioenergy, and other miscellaneous industrial applications. The review also highlights the recent research trends, technological innovations, and existing obstacles for converting tall oil into efficient biofuels and diverse industrially useful derivatives. Tall oil and its various derivatives are expected to greatly contribute to the circular economy through several key and niche applications, primarily due to their biodegradability, renewability, and environmentally friendly characteristics. Moreover, tall oil is abundantly available as a cost-effective by-product from the Kraft paper manufacturing process, making it an attractive and sustainable raw material for a wide range of industries. Considering its eco-friendly nature, chemical versatility, and potential for use in multiple commercial applications such as coatings, adhesives, lubricants, resins, surfactants, and biodiesel production, the tall oil market is poised to grow substantially at a rapid pace in the near future. Continued research efforts, industrial collaborations, and advancements in refining and conversion technologies are expected to further enhance its quality, yield, and commercial viability, positioning tall oil as one of the most promising renewable resources capable of reducing dependence on fossil fuels and promoting sustainable industrial development worldwide.

Keywords: Biofuels, Distilled Tall Oil, Kraft Process, Lignocellulose, Tall Oil, Tall Oil Fatty Acid

INTRODUCTION

Tall oil is a by-product of the Kraft pulping process in the paper and pulp industry and is recovered from a black-colored liquid. Tall oil is a valuable bio-based industrial product earlier derived from coniferous trees like pine. The term “tall” is a Swedish word *tallolja*, which means pine oil. As the world is moving towards sustainable and renewable resources, tall oil has generated significant attention due to its numerous industrial applications and as potential material for bio-based alternatives in various industries. The energy demand is growing at a very fast pace due to a booming population and rapid industrial development globally. The estimated global energy demand has risen 4.6 % in 2021 and greenhouse gas emissions further added to this ever-growing energy demand [1, 2]. Growing wars and tensions

***Author for Correspondence**
Sandeep Rai
E-mail: sadeep1964@yahoo.co.in

[1]Doctoral Progress Committee Member, UPL University for Sustainable Development, Block No. 402, Ankleshwar- Valia Road, Taluka- Valia, District- Bharuch, India.

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in large fossil fuel producers like Russia and Iran have further put pressure on the energy sector and thus fuel prices are witnessing a surge. The rapid consumption and steep decline in non-renewable fossil fuel resources, dangerous environmental predictions, and regular increase in fuel prices have pushed researchers to develop sustainable sources of energy to preserve fossil fuel reserves for our future generations [3–5]. Many countries are striving for carbon neutrality targets within the next 30 years [6]. The bioenergy resources are drawing attention by sequestering carbon to create a sustainable and renewable carbon cycle.

Lignocellulosic natural materials are the largest proportion of biomass on earth, which are the potential feedstock for biofuels and are capable of reducing reliance on conventional fossil fuels [7]. Crude tall oil (CTO) is a by-product of the cellulose-extracting Kraft pulping process; this process is utilized by most paper and pulp manufacturers and produces tall oil at a yield of around 30–50 kg/ton of pulp [8]. A readily available and convenient resource, Crude Tall Oil is produced globally as a by-product mainly through the forestry or wood industries. With the long-existing infrastructure and steady production of paper and pulp in huge quantities, it is very convenient to produce CTO with consistent quality and makes it more conveniently and abundantly available than any other resources for fuel production. Current CTO production was estimated to be around 1.85 million tons per annum in the year 2019 with a projected increase to 2.26 million tons per annum by the year 2030 [9]. Over 50% of global CTO production is consumed for producing bio-chemicals commercially, with an estimated demand of 1.48 million tons per year in 2019 and 1.56 million tons per annum by 2030 for bio-chemicals production [10]. Lately, for many years, the remaining CTO has been considered as a potential and cheaper resource for biofuels production due to its existing supply and low cost compared to other bio-oils, such as vegetable oils [11]. Tall oil, therefore, can be a viable solution to achieve eco-friendly and renewable biofuel objectives. Tall oil, among other natural and vegetable oils, is essential for long-term sustainability to replace the multi-billion tons of fossil fuels yearly consumed worldwide. It may be highlighted that extensive biofuel research and development work to develop biofuels based on second-generation biomass like castor, jatropha, and neem oil and third-generation biomass i.e., algae, is underway to meet the need for a carbon-neutral future [12].

Tall oil contains high fatty acids and is very suitable for forming hydrocarbons in the range required for transportation fuels. It may be worth mentioning that petroleum-based fuels are a mixture of more than hundreds of hydrocarbons, and also contain various impurities, such as sulfur and nitrogen compounds, aromatic hydrocarbons, metals, and crude residues or pitch [13]. On the other hand, biofuels/crudes are expected to have relatively very low aromatics, metal, and sulfur contaminations. However, biofuels will have lower heating values, higher oxygen content, viscosity, pour point, cloud point, and nitrogen contamination that pose problems in their use as fuel against fossil fuels [14]. Biofuels are expected to have a low environmental impact as they are completely biodegradable [15]. These properties allow tall oil-based fuels to release considerably less CO (carbon monoxide), sulfur emissions, suspended particles, and smokes during their complete combustion than petroleum fuels [16]. The global energy demand is expected to increase exponentially in coming years; thus, there is an urgent need to identify and develop multiple biofuel sources to effectively support the transportation industry and reduce their reliance on fossil fuels [17]. This fact has prompted researchers to take up studies exploring the feasibility of tall oil conversion to biodiesel [18].

Tall oil – a renewable by-product of the paper and pulping industries – has numerous opportunities and applications, but its availability is always in surplus and not fully utilized as a bio-economy-contributing material [19]. This review will briefly describe its recovery from woody mass to end fuel products, its varying composition, production, refinement, and applications of tall oil as well as synthesis.

PRODUCTION OF TALL OIL FROM BLACK LIQUOR

Source and Extraction

- Tall oil is mainly recovered from the black liquor [20] – a byproduct of the Kraft pulping process, in which wood chips are digested in a mixture of sodium hydroxide and sodium sulfide to solubilize all ligno materials except cellulose fibers which are used for making

paper and paper boards. This process generates black liquor, a solution containing precious chemicals, residual pulp, and the pitch from the wood. The general process of tall oil production from black liquor is shown in Figure 1.

- Resin acids, fatty acids, and unsaponifiables are converted into water-soluble sodium soap by saponification.
- The sodium soaps of fatty and rosin acids float on top of the black liquor.
- The soap is skimmed and acidified using concentrated sulfuric acid to produce crude tall oil (CTO) containing a mixture of fatty and rosin acids.

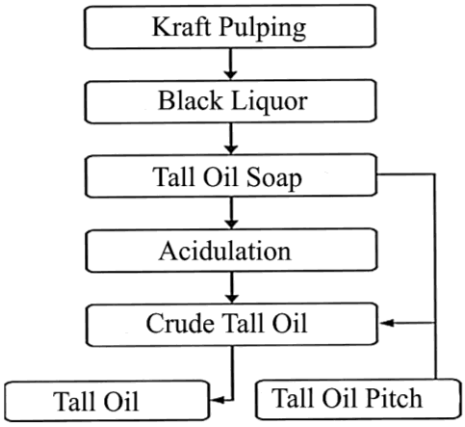

Figure 1. Process of Recovering Tall Oil by Black Liquid generated during Kraft Process.

Refining

Crude tall oil is then refined by fractional distillation and separation to produce different grades of tall oil as follows.

- *Distilled Tall Oil (DTO):* contains mainly fatty acids and rosin acids.
- *Tall Oil Fatty Acids (TOFA):* contains linoleic and oleic acid.
- *Tall Oil Rosin (TOR):* Contains mainly rosin acids such as abietic acid.
- *Pitch:* Heavy fraction left over during distillation and finds use in fuel applications.

APPLICATIONS OF TALL OIL

Tall oil and its derivatives are versatile and are used across many industries [21]. Numerous industrial applications of tall oil and its derivatives are depicted in Figure 2.

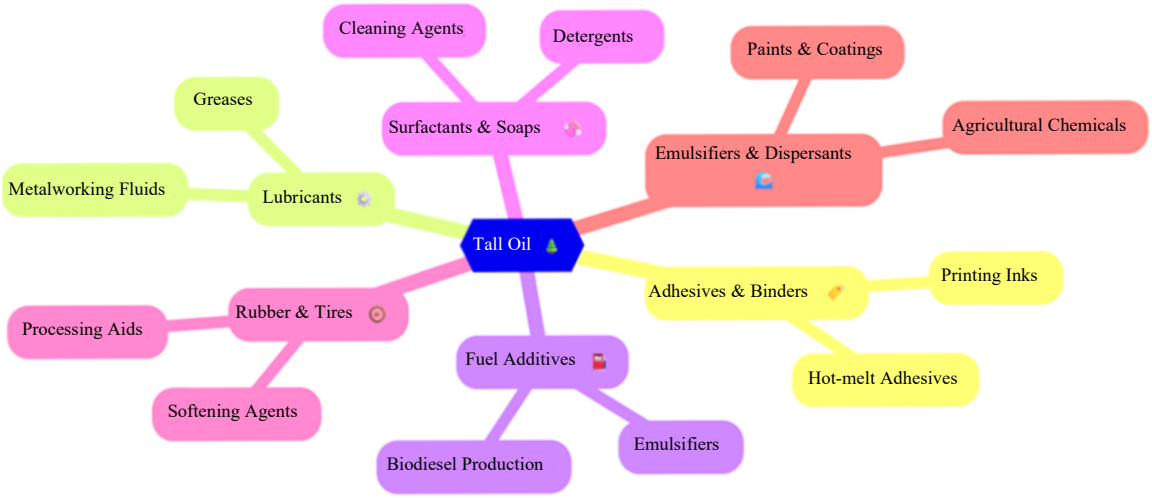

Figure 2. Industrial uses of Tall Oil and Its Derivatives.

Chemical Industry

- *Adhesives and Sealants:* Rosins provide tackiness and thermal stability [22].
- *Inks and Coatings:* Used for gloss and pigment dispersion [23].
- *Surfactants and Detergents:* Fatty acids are ideal for emulsifiers [24].

Biofuels

- *Renewable Diesel and Biodiesel:* Tall oil fatty acid and crude tall oil are promising feed stocks [8] for diesel and other biofuels.
- *Jet Fuels:* Emerging research on using tall oil for aviation fuel is gaining momentum [25].
- *Lubricants:* Biodegradable lubricants and additives may benefit from tall oil's thermal and oxidative stability and thus improved performance [26].
- *Construction and Asphalt:* Tall oil pitch used in asphalt emulsions and roofing products has been found to improve binding and waterproofing [27].
- *Agriculture:* Tall oil acts as a base for pesticides, herbicides, and growth regulators [28].
- *Personal Care and Cosmetics:* Tall oil fatty acid-derived esters are used in soaps, shampoos, and lotions [29].

GLOBAL MARKET OVERVIEW

Production Hubs

1. *United States:* Largest producer of tall oil, especially in the Southeast.
2. *Scandinavia (Sweden, Finland):* Significant producers due to their vast pine forests and advanced pulp industries.
3. *Russia and Canada:* Emerging key players with growing production capacity [30].

Key Global Producers

- Kraton Corporation
- Georgia-Pacific Chemicals
- UPM-Kymmene
- Forchem Oy
- Eastman Chemical Company

Tall Oil Market Size and Growth

- Estimated global market size of tall oil was USD 1.2–1.5 billion (as of 2024) [31].
- *CAGR:* Tall oil global market projected 4–6 % growth from the year 2024 to the year 2030.
- Key drivers for rising global market demand are emerging applications of tall oil in biofuels, green chemicals, and coatings sectors.

Trade and Supply Chain

- Crude tall oil and its derivatives are freely traded worldwide because of the eco-friendly nature of tall oil.
- Sustainability certifications like ISCC are increasingly demanded in Europe by customers.

Sustainability and Environmental Impact

- Tall oil is renewable, biodegradable, and non-food competitive [32].
- Tall oil use strongly supports circular economy principles by developing value-added materials from pulp mill by-products – black liquor.
- It is worth mentioning that CO2 emissions from tall oil-derived fuels are significantly lower than fossil fuels.

Challenges

- *Feedstock Limitations:* As tall oil bulk production is dependent on the pulp and paper industry, it will limit growth in areas without strong forestry sectors.

- *Price Volatility:* Tall oil may compete with petroleum-based counterparts.
- *Complex Refining Process:* Tall oil commercial production requires capital-intensive distillation and thus is a limitation for its commercial uses.

FUTURE PROSPECTS

Emerging Technologies

- *Catalytic Conversion:* Advanced methods to convert CTO into high-value chemicals.
- *Fermentation Pathways:* Using tall oil as a carbon source for producing bioplastics or surfactants.

Policy Support

- Several beneficial and supportive policies are initiated by the EU and US to promote uses of tall oil in commercial sectors like the EU's Green Deal and U.S. Renewable Fuel Standard (RFS), which encourage tall oil biofuels [33].
- Carbon taxes and emission caps may push industries toward tall oil-based alternatives.

Market Opportunities

- *Asia-Pacific:* Projected major player for growth of tall oil market due to rapid industrialization and focus on development of sustainable products [34].
- *Aviation:* Growing demand for Sustainable Aviation Fuels (SAFs) could prove to be a game changer to greatly enhance the position for tall oil as a key feedstock.

CONCLUSION

Tall oil is considered a very promising eco-friendly feedstock and stands at the intersection of sustainability, industrial utility, and economic potential. As industries and governments are moving towards greener and eco-friendly alternatives, tall oil's industrial applications – from adhesives to advanced biofuels – are likely to expand at a very fast pace in coming years. The key to making this a reality and unlocking the full potential of tall oil in commercial applications lies mainly in innovation, supportive strategic policy frameworks, and increased refining capacity of crude tall oil globally.

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