LUT UNIVERSITY
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SORTING OF IMPREGNATED WOOD

26.10.2021

Examiner(s): Professor Timo Kärki
D. Sc. Marko Hyvärinen

ABSTRACT

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Keywords: Impregnated wood, Untreated wood, Wood sorting, Cr, Cu, As, XRF, LIBS, Line construction, Screw conveyance, Belt conveyance, Metal detection, Chemical additives.

This thesis aims to learn about the stages and materials involved in impregnating wood and enhancing their capabilities by doping chemical impurities with an introduction to pre-treatments and pressured impregnation methods. Post impregnation the wood is transported through a conveyance system, In this research, a comparison of a cost-efficient and economical line construction machinery suitable for sorting the impregnated wood material is evaluated, along with a qualitative experiment carried out on impregnated wood from a previous study on various laser sorting efficiencies XRF and LIBS are also studied that could detect the metals i.e. As, Cu, Cr in the impregnated wood and a detailed analysis of detection of impurities is identified in the following study. According to the following study, LIBS shows significant advantages over XRF, the subsequent belt conveyance is recommended as the main method of transporting wood products.

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All my accomplishments would not have been possible without the blessings of God, for which I am eternally thankful and obliged.

Raja Nishanth Reddy

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Lappeenranta, Finland

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LIST OF ABBREVIATION

AACEI	American association of international cost engineers
ACA	Ammonical copper arsenate
ACQ	Alkaline copper quat
ACZA	Ammonical copper zinc arsenate
As	Arsenic
B	Boron
Be	Beryllium
C	Carbon
Ca	Calcium
CAD	Computer aided design
CAPEX	Capital expenditure
CBA	4-Carboxybenzaldehyde
CCA	Chromated copper arsenate
Cl	Chlorine
CPS	Centimetre per square
Cr	Chromium
Cu	Copper
DPP	Digital pulse processing
ED-XRF	Energy dispersive X - ray fluorescence
EU	European Union
H	Hydrogen
ICCD	Inter-component communication
IED	Intelligent electronic device
IRGWP	The international research group on wood preservation
Li	Lithium
LIBS	Laser induced breakdown spectroscopy
LOD	Limit of detection
MCQ	Micronized copper quat
N	Nitrogen
Na	Sodium

NIR	Near infrared spectroscopy
O	Oxygen
OPEX	Operational expenditure
PCMCIA	Personal computer memory card international association
SNAEP	Superior wood engineering practice
SSDs	Silicon drift detection
TFT	Thin film transistor
Ti	Titanium
UV	Ultraviolet
VIS	Visual identity system
VUV	Vacuum ultraviolet radiation
W- coil AAS	W-coil atomic absorption spectroscopy
WD-XRF	Wavelength dispersive X - ray fluorescence
XRF	X-ray fluorescence

1 INTRODUCTION

The use of impregnated wood has witnessed tremendous growth over the past three decades. Many industries depend on wood, such as buildings and furniture. It's particularly suitable for architects and designers because of its ability to be regenerated, its plasticity, transformability, and its mechanical properties. The properties of wood may be improved by impregnation or by coating. [1]

More treatments have been used in recent decades to increase wood strength, minimize flammability, or improve mechanical properties. physical and/chemical therapies should be completely transparent, while at the same time in a reactor, an injection of high pressure will accomplish impregnation. Several methods, such as Lowry, Rüping, or Bethell, use varying pressure and vacuum cycles. [1]

Wood composite material has a high strength to weight ratio, high efficiency in acoustic absorption, heat resistance, is simple to work with and nail down to connect, has good chemical resistance, and the most important feature of wood is that it can be recycled. While possessing such great resources, they may burn rapidly and be destroyed by deadly termites. To address this issue, the exterior of the wood may be coated or impregnated. Since the wood has been impregnated, it becomes nine to ten times stronger. un-impregnated products, that are left in unpretentious conditions for five years, are vulnerable to damage down. [2]

X-ray fluorescence (XRF) is a kind of thermal spectroscopy (X-ray). Scanners using X-ray fluorescence are used to determine the elemental makeup of materials. X-ray fluorescence analysers calculate the quantity of fluorescent (or secondary) X-rays produced by a sample when stimulated with a primary X-ray source. Each element in a sample generates a unique pattern of X-rays that may be used to classify it. [3]

Each element has its own unique XRF spectral lines, which makes portable XRF analysis a very reliable technique for measuring and characterizing each element. Over time, both methodological and instrumental X-ray fluorescence has made steadily. [3]

Recent advances in research, software development, and quantification methods have acted as a stimulant for the study and use of X-ray fluorescence spectroscopy, resulting in major new advances. Recent technological advances, such as table-top devices that use new low-power microfocus tubes, novel X-ray optics and detectors, and easier access to synchrotron radiation, have made the collection of XRF data from elements with low atomic numbers. Compact and portable XRF instruments have enabled a more mobile use of XRF in archaeology and process management. Synchrotron radiation generates high-intensity excitation and a broad range of spectra, depending on the radiation's energy. [3]

1.1 Objective of the study

The primary goal of this study is to examine impregnated wood sorting and sketch up a plan for the best feasible method. The wood industry is currently incorporating line construction and sorting technologies, as well as different equipment such as XRF and LIBS. These setups can detect elements such as Cu, As, and Cr in impregnated wood.

1.2 Legislation

About 6.3 million and 6.5 million kilotons of treated wood are made in Europe annually, Europe's forestry sector has the pressure treaters market for the most. Sleepers are trees that account for 21% of the total production and small round wood demand. Figure 1 indicates that 44% of the demand is used for construction; small round wood represents approximately 44% of the total; construction account for 15% of the total amount of small round wood that is needed. About 71% of the wood is treated by water-based chemicals, 11% is creosoted, whilst most of them are poles and sleepers (for temporary construction), with creosote-like materials, for example, temporary buildings such as residences use 80% of this wood's existing structures are water-treated, 80% of the existing structures are applied, like buildings (see Figure 1). As the rules have been stricter, bed wood impregnation has become less frequent. For example, bed impregnation is limited to wooden sleeper lines, such as in the past, under previous regulations, but the use of non-wood materials such as concrete sleepers for new train tracks has seen a decline. Creosote has been used for more in Europe, and thus increased use of it has been confirmed to have a dramatic effect on ironwood and pine poles. A significant portion of this is exported and sold to nations outside the European Union. [4]

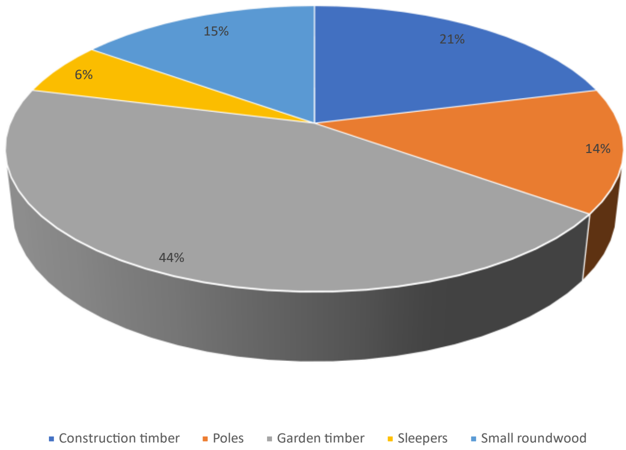

Figure 1. EU production of wood preservation industry classified by product form[4].

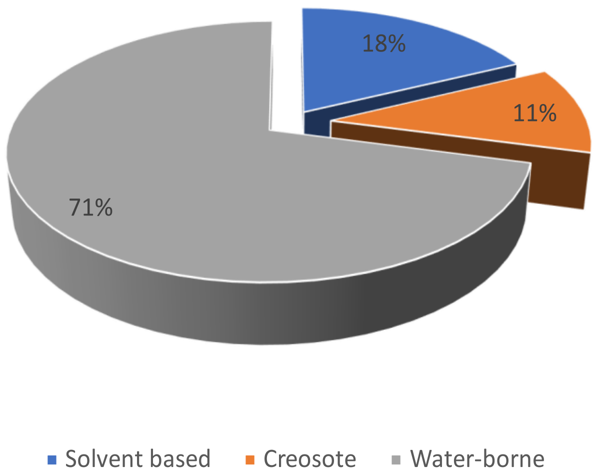

Figure 2. EU production of impregnant categorized wood sustaining the industry[4].

About 2.12 million m^3 production of impregnated wood in the Nordic countries in 2012 was produced for the wood preserving industry. There is approximately 1/3rd of the total European supply of impregnated wood for sale in the Nordics. See Figure 2 for information on total pressure-treated wood production in different Nordic countries, and the number of installations in each country on its own line is listed below. [4]

It is estimated that in the Nordics, Sweden is the most prolific producer of pressure-treated wood, and Denmark and Norway tie for second place. Many of the production facilities in

Iceland are not utilizing the large scale of injection (a production method that necessitates the use of an impregnation plant). [4]

Additionally, in Figure 3, you can see the number of different plant species in various countries. Around half of these plants have a maximum daily production capacity of more than 75m^3, which means that IED has been unable to make an impact on them. These do not only include some of the largest computer installations, but also some of the smaller ones; furthermore, there are several unlisted computer configurations not included in these numbers. [4]

The plants operate during different times of the year with different capacities are worth noting. Typically, in the months with the highest sales and production, there is a high level of expansion; meanwhile, in other months the plants produce varying amounts for distribution to various markets for exports. [4]

* This graphic depicts a land-based production plant capable of generating between 2500 and 5000 m^3 of impregnated wood per year.

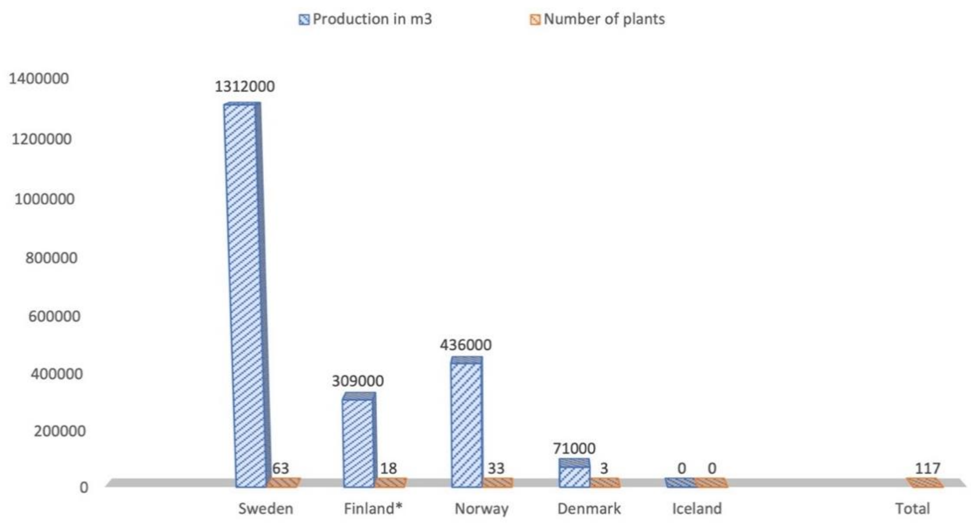

Figure 3. Impregnation plants and their output in the Nordic countries during 2012 [5].

Expanded in Chart 2: This indicates the geographical distribution of the various products offered by the Nordic wood preservation industry Industrious trees are doing better in Sweden, at about 92%, in Norway, about SNAEP (superior wood engineering practices), are available. Also, in Europe, most industries pressure-treated wood is going for around 76% of the market price of naturally harvested trees. 21% of all the population is employed in the forest industry[5], but in Norway and Finland, the figure is approximately 3% of the population are people impregnated in industry In Figure 5, the Nordic wood preserving industry is mapped out according to the nature of the applied compaction technique. [5]

About Europe, a comparable rate of application of water-based preservatives is also exists in the Nordics. It is worth noting that a significant portion of Swedish manufacturing is exported outside the nation. Despite the many pressures to treat lumber as a water-borne alternative, the use of flow-coat paints has come to the fore as the preferred method for most wood window and door production in Denmark. [5]
In the case of Denmark, flow-coating was difficult to get and thus, supply was an issue.

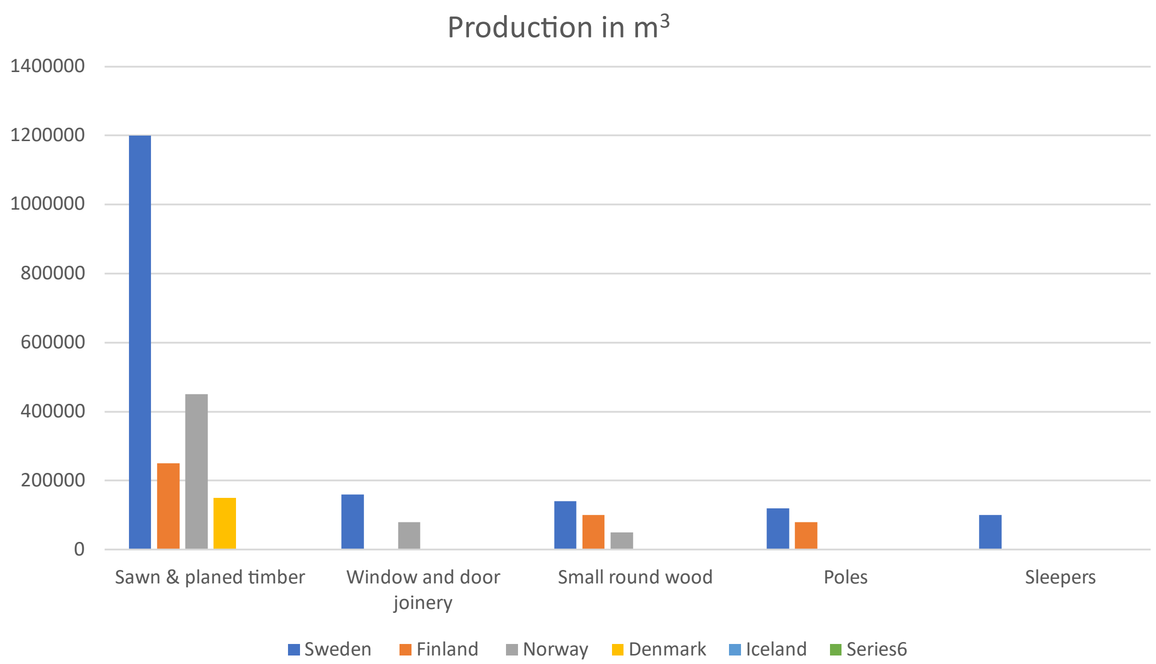

Figure 4. Wood preserving industries in the Nordics classifies by the type of product in 2012[5]

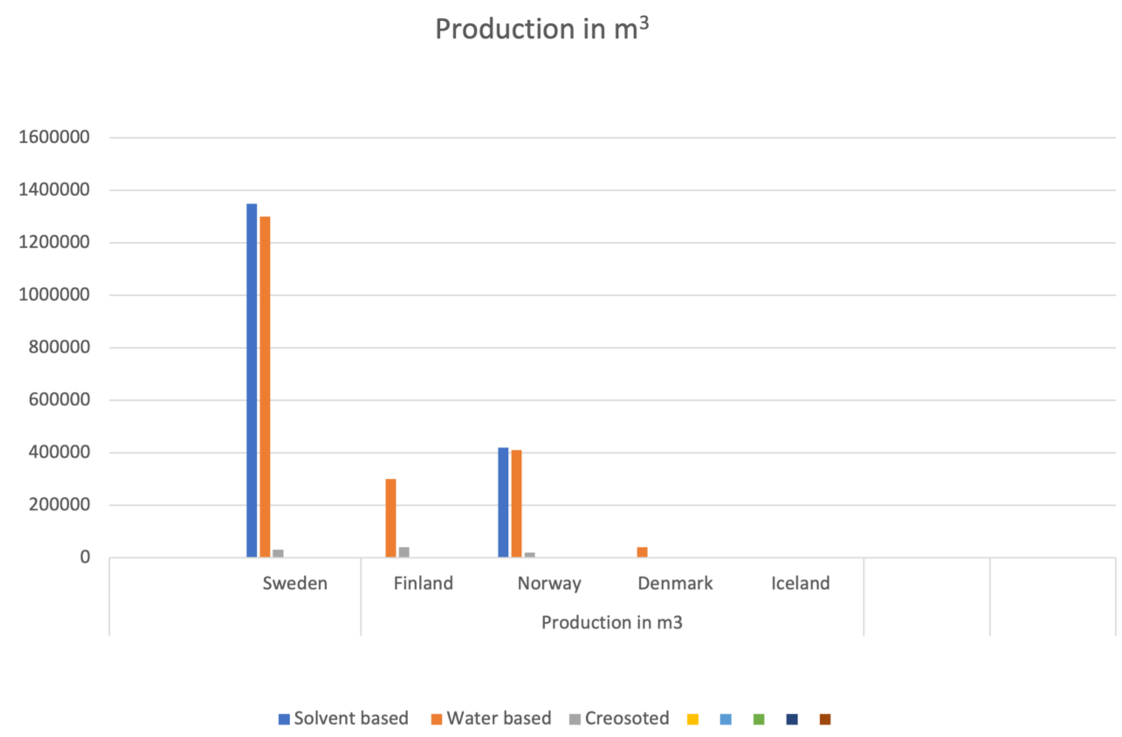

Figure 5. Statistics from 2012 on the wood preservation business in the Nordics classified by impregnated type.[5]

1.3 History of impregnated wood

Wood has been known to be impregnated with various chemicals to improve its characteristics for thousands of years. Pliny the Elder said Diana of Ephesinaeina existed by impregnating wood sculptures with clay. To prolong the sculpture's life, holes were bored into the "Nard" (extract of plant Nardostychos from India). It also used asphalt, olive, and soybean oils. Leonardo (1452–1519) used mercuric chloride as a drawing primer and arsenic oxide (called orpiment) for portraiture. After Homberg recommended mercuric chloride to the cabinetmakers in 1705 to control bore out their timber casework, mercuric chloride was used. Sal sedatum is necessary nowadays owing to boric acid replacement (which was made possible due to research on it in Homberg). Impregnating mercury di-chloride was developed in 1832 by an Englishman named Kyan (The Kyan Process). Copper sulphate was also utilized in the paper industry. In 1836, Bethell developed a technique for introducing coal tar creosote to the impregnation business. Bethel, an engineer at the time, is said to have developed the Bethel pressure impregnation method for creosote treatments. After the first vacuum, the vial was injected with a preservative and sealed under high pressure. Creosote was cheaper in Europe than in England. But it was utilized. [6]

The Englishman Burnett (1782–1834) added zinc chloride to their treatment, which had been utilized for many years by traditional European doctors. There are several drawbacks to utilizing zinc chloride as topical therapy, such as its ease of leaching and efficacy. So, in the presence of creosote, zinc chloride was added, enabling it to expand. Copper naphtate has been used to prevent wood rot since 1889. In 1902, Max Thorek, an Englishman in pursuit of pure mother liquor, marketed empty gene processes [6 [1] [2]]. The method involves decreasing the air pressure until the container is full, then increasing it to maintain the solution's concentration. The preservative “dumped” due to the expanded-cell technique producing significant retention of the cell pressure (Bethel Process). [6]

It is one of the greatest improvements in impregnation. This simple business approach reduces creosote use while keeping expenses down (also for other preservatives). Then C.B. Lowry obtained a patent for the Lowry Process, which uses ambient pressure as the starting pressure. Academician Basilius Malenkovi discovered fluorides in 1901. K. Wollmann discovered that sodium fluoride may be used as a wood preservative. Arsenate and arsenic have been shown to kill bugs and fungi. The AWA has been around for 100 years. The first impregnation at Beznice (Czechoslovakia) started in 1934 and continues now as Sublima (which means extend). Bubla invented and patented the "Sublimate" method. [6]

This component has limited solubility and great protection, resulting in a product with good expansion but poor corrosion resistance. The preservation method included sodium fluoride, potassium dichromate, and sodium arsenate, as well as a salt of sulphate, dichromate, and sodium di-nitro-phenol. [2]

The root system or high moisture content wood was used to penetrate the forest. In 1938, Kames was the first to patent CCA (chromated copper arsenate). In 1950, the biggest arsenical preservative, ammonium copper arsenate (ACA), was restricted. The International Research Group on Wood Preservation (IRGWP) was founded in 1969 with the aim of providing knowledge on damaging chemicals and motivation for future wood preservation research [2]

1.4 Materials and chemicals used for impregnation of wood

To a large degree, the many implementation methods will follow the requirements of transport of active component delivery and delivery of an active compound to targeted wood locations. Various (customer requirements, the technology available, etc.). When assessing impregnation efficiency, the main parameters involve the capacity to maintain preservatives (or resistance to non-pressure impregnation) in kg/m or g/m^2 (apparent of resistance to water penetration) and how far they are gotten at the point of injection (pressure injection) versus below the surface of the base material.

According to Freeman, [7] the treatments can be divided into non-pressure and pressure, and it usually requires carrying out pre-treatments as we will include all the methods in the coming paragraphs.

1.4.1 Pre - treatments

The optimum time period between felling and milling is no more than a fortnight. For prolonged times, scraping or spraying uncovered end-grain of logs with a biocide such as copper-8 quinolinolate is advised. Usually, the poles are debarked prior to drying.
With few exceptions, wood should be dried to the point of fibre saturation (25-30%) or below prior to the impregnation procedure. Kiln-drying is more common for lumber because it is not confined by the dimensions of treated timber. For big timbers, air drying is used (railway sleepers, poles, etc). This is a more time-consuming process (e.g., spruce poles require about 3 months of air-drying depending on the season). Drying improves the penetration and retention of preservatives. It is also important for cracking, which happens often prior to the impregnation procedure. Cracks in the service of timber can occur if the timber is not properly dried. These cracks may reveal untreated parts of the wood, creating an entrance point for wood-destroying insects or fungi. [8]

Figure 6. Air drying poles on a stockyard in Idaho, USA [10].

Sleepers made of hardwood are more prone to splitting. Irons, anti-seasoning irons are also, in the end-grains of the sleepers, to prevent the cracking that can occur when stacking for air-seasoning is finished [9]. Usage of non-cracking, continuous, end-grain metal irons is not necessarily guaranteed to avoid extensive damage, and the impact of continuous use can also accelerate end-grain damage (shown in figure 7). Since their continued usage by various railroads implies that these are still seen as being significant, it suggests that there are those who are concerned about reducing the risk of passenger accidents from end cracking. [10]

Figure 7. Peeling and perforation of wooden poles [12]

Incising, drilling and milling are often for species like spruce poles (Shown in figure 7&8), or something that is fully impermeable Douglas fir, larch, etc. Drilling can often be used to provide support for wooden sleepers. [10]

Figure 8. Incising of wooden poles [13].

1.4.2 Pressure Impregnation

The most popular and efficient approach is impregnation, which blends vacuum and pressure (See Figure 9). The procedure necessitates the use of specially designed plants equipped with pressure vessels, air compressors, vacuum pumps, and measurement and storage tanks, among other components. There are two types of pressure impregnation: full-cell and empty-cell. Treatment intervals come in several configurations, and Figure 9 shows a diagram of mentioned and elaborated processes that are conventionally used these days.

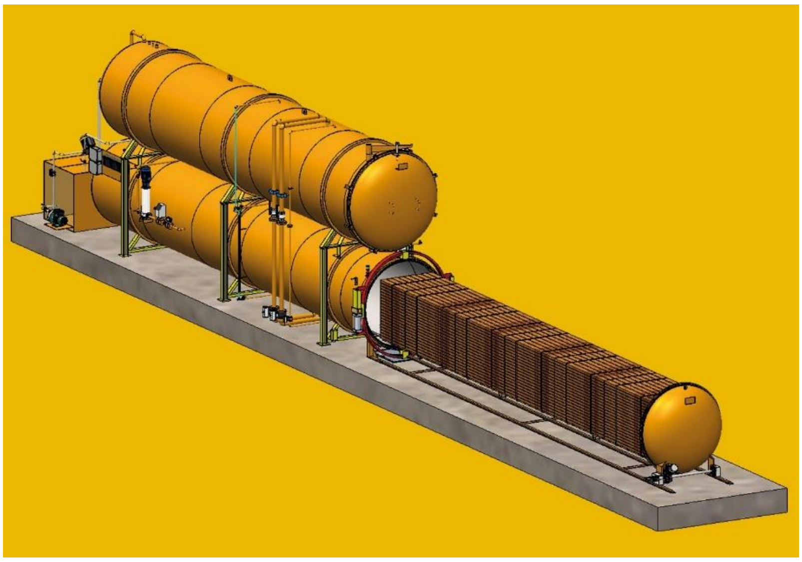

Figure 9. A Virtual representation of charging timber into the vessel of vacuum pressure impregnation chamber [14].

Bethell process starts with an initial pressure of at least -85 kPa or most often 90 kPa and continuing for at least 15 minutes with permeability and cross-section dimension after treatment Next, the solvent is pumped into the treatment vessel, where it then mixes with the wood and is uniformly distributed across the system. Subsequently, the pressure (around 800 to 1400 kPa, above atmospheric pressure) is applied for 1 to 5 hours or as long as needed to increase the pore volume and pore size. Although the pressure is always applied, the substance does not encourage any more water into the timber until the concentration of preservative becomes insignificant or there is no water absorption by the timber. So the vessel is vesicle is vented and the strain is removed, allowing the expansion solution to bubble up. The last move is to guarantee the preservation of the wood's preservative amount remains low enough such that any preservatives added to the surface may not kick back into the solvent, and bleeding happens, may not compete (Frequently used for water-based preservatives). In the example above, the waterborne preservatives, I suggest you use normally applied at room temperature, but Eg. creosote is heated to 60-120 °C to boost the viscosity and hence to penetration. Permeable timber can have retention of up to 600-700 kg moisture can be retained up to their point of moisture capability. As the methodology of producing creosote is used, the retention of creosote ranges from 80 kg/m3 and 250 kg/m3. [14]

Vacuum treatment (full cell) is used on permeable wood types and treated wood with limited dimensions. The method starts with vacuuming, progresses by impregnation at atmospheric pressure, and concludes with another vacuum. [14]

Rueping (empty cell) was initially formulated for the treatment of creosote and is still used for this purpose. The procedure is started by applying air pressure, which is usually between 150 and 400 kPa for 10 to 60 minutes, depending on the permeability and size of the treated wood. Setting the air pressure and length of the procedure at the start is the most appropriate and practically the only way to affect retention. The preservative is injected into the impregnation vessel at a pressure of 800-1400 kPa without releasing it. Following the release of pressure, the vessel's preservatives will be extracted. To alleviate moaning, a final vacuum (about -75 kPa) is implemented for about 10 minutes. Creosote is only ideal for usage at elevated temperatures (100–120 °C). Permeable timber can retain 40-50 per cent of its maximum retention after rueping care. For eg, whereas the Bethel method may achieve creosote retention of approximately 250 kgm^3, the Rueping method achieves retention of approximately 110 kgm^3 at the same penetration depth. [14]

Double Rueping (empty cell) is the sequential application of two single Rueping methods (cycles) for a shorter time span of the impregnation pressure phase. The second cycle features elevated friction and a longer length. The procedure is mostly used to creosote-treat beech railway sleepers. [14]

Lowry's (empty cell) procedure guarantees optimum penetration with minimal preservative retention. This mechanism is caused by air pressure alone, not by vacuum or pressure. The subsequent measures are identical to those of the Rueping process, namely pressurization and final vacuum. The system is most effective with permeable woods such as pine. Additionally, it is used to impregnate oak sleepers. The advantage of this approach is that it results in reduced prices for the plant's technological facilities.

The oscillating pressure mechanism penetrates preservatives into greenwood by repeated applications of high pressure and vacuum. The duration of the loops gradually increases from approximately 1 to 7 minutes. The number of cycles ranges between approximately 40 and 400, depending on the permeability and dimension of the treated wood. [14]

1.4.3 Non-Pressure Impregnation

Though brushing and spraying are quick and inexpensive treatment methods, their penetration depth and retention are extremely restricted. Cross-grain penetration is restricted, however, some penetration all along the grain is likely.

When opposed to brushing or spraying, dipping for a few seconds will improve end-grain penetration. The end-grain of pine sapwood will penetrate to a depth of 25 to 75 mm. [15]

Often known as "soaking", the web takes longer for water to wet but is the same in that it is called "dipping" for a change in immersion time. A significant number of sawmills and woodworking machinery features this method for smaller diameter poles and wood products[15]. The resulting sapwood of pine after having soaked in a concentrated preservative solution for 24 to three to 48 hours had been evenly distributed, ranging from 32 to 96 kg per cubic meters.

The diffusion process is used on newly sawn reclaimed lumber with a moisture content greater than 50%. (e.g., poles or construction timber). A water-based solvent boron salts, fluorine compounds are rubbed onto the wood's surface, where it diffuses mostly to the sapwood. The movement of substances occurs due to a concentration gradient through the material, which allows the solution to shift from a position with a higher concentration to a location with a lower concentration. This approach is generally used for impermeable organisms. [15]

On freshly cut green logs with bark, the Boucherie process (sap displacement) is applied. The tank containing preservatives is suspended from scaffolding (approximately 10-15 m in height), and the logs are laid out on the field (but a little higher than the top). A secure metallic cap attached to the clean surface of the butt is connected to the tank by piping. The cold and hot bath technique is a physical impregnation process in which the wood is immersed in a hot preservative bath and then in a cold preservative bath. Air spreads in wood cell cavities exposed to a hot wash. Due to the partial vacuum provided by air contraction after immersion in cold baths, the preservatives infiltrate the wood. [15]

2 MEASURING TECHNOLOGIES

This section provides an overview of the technologies and their recent advancements, as well as analytical techniques and empirical data of XRF and LIBS.

2.1.1 X-ray Fluorescence (XRF)

Recent developments in XRF technology Typically, conventional research begins with the processing of a wood sample from a distant location, and it’s transported to an investigative laboratory. Prior to analysis, the wooden sample should be processed in specific environments. Generally, an illustrative preparation is expected prior to performing with instrumental measurements. Although conventional laboratory-based analytical methods may provide precise and reliable results, they are typically tedious and expensive. Although, certain applications include on-site & in-situ processing (as well as field applications), and certain analytical objectives (for example, artworks that are delicate in nature) are not amenable to disruptive sampling. Because of these needs, field analytical chemistry and portable analytical equipment have both been developed. Numerous methods from atomic spectrometry have been modified for use in portable instruments.

Laser-induced breakdown spectroscopy (LIBS) as well as W-coil atomic absorption spectroscopy (W-coil AAS) under the heading of on-field instrumentation of atomic spectroscopy. Latest developments in X-ray fluorescence (XRF) spectroscopic analysis that’ll be discussed in this research work, with a focus on field applications. [16]

The electron from a higher energy shell will fall down to fill the inner shell's vacuum, and the excess energy will be emitted as an x-ray photon (fluorescence) with the atom's wavelength. The XRF function is known to as a K-line or an L-line depending on the inner shell. Because the XRF wavelength is regulated by energy levels of electrons in the atom's inner shells rather than valence shell electrons, the technique is largely independent of the atom's chemical state. Thus, XRF is a commonly used qualitative method for analysing materials of various kinds. Quantitative calculations are more challenging since the sample structure influences the penetration depth of the stimulating particles or photons, and the amount of scattering of the XRF photons. However, matrices heavily influence quantitative calculations. [17]

Although this is true, XRF is a non-destructive, simultaneous multi-element technique that has a wide dynamic range ranging from 100 per cent to mg/g with a typical relative accuracy of less than 1 per cent. It may be used to determine the composition of a variety of materials. This well-established analytical technique has been expanded to include samples from the landscape, geology, archaeology, and metals and alloys, among other things. Even with very little sample preparation time, XRF can conduct qualitative, semi-quantitative, and even quantitative analysis on a wide range of samples including liquids, powders, solids, and thin films in only a few minutes. XRF can currently distinguish between elements with atomic numbers (Z) ranging from 11 (Na) to 92 (Ca), depending on the precision of the excitation source and the detector used in the analysis process (U). In addition, the ease of use and versatility of XRF has raised it to the rank of a useful field-portable analytical tool. [16]

In any case, the analytical efficiency of XRF is dependent upon on analysis time per specimen and the reference normally used with increased analysis time, both identification limits and accuracy boost. The calibration model would be more accurate if the reference criteria have matrix properties that are like the analytical sample.

A calibration curve may be built empirically utilizing a set of previously gathered site-specific calibration criteria that have been independently verified using reliable techniques, which is possible because of the matrix dependency of XRF signals. This technique's disadvantage is its difficulty. Alternatively, fundamental parameter techniques have been established that may remove the need for site-specific criteria. These methods include creating theoretical calibration coefficients. The protocol may introduce errors or biases depending on the integrity of the information used in this model. Therefore, modifications could be required depending mostly on analyses of approved products. [16]

Following is a brief comparison of the two calibration techniques, which will be given in Table 1.

Table 1. Calibration based on empirical data vs. parameter calibration based on primary data in XRF [17].

	Empirical data calibration	Primary parameter calibration
Standardization	These samples must be verified by independent lab testing techniques; processing and laboratory analysis are also costly.	The sample composition, including unmeasured balance, must be known or estimated; nevertheless, pure elements and readily accessible approved test materials can be utilized as criteria.
Calibration	The XRF should be optimized against site determined requirements. To model and compensate for matrix results, a significant number of standards might be needed.	In addition, the FP quantification technique does not need site-specific calibration and does not require normal concentrations to bracket the site's values.
Precision	The outcome would be reliable and directly equivalent to laboratory research if a successful calibration model is used.	The FP model can include preliminary "fine-tuning" with accredited reference materials.

Primary parameter procedures may be used for portable XRF instruments with any adjustment and optimization.

Other methods for improving the efficiency of XRF spectrometry are usable. When calibrating the instrument to mainly flat specifications, samples with uneven surfaces can cause issues. By analysing the scattering spectrum emitted by the sample, this obvious mismatch may be avoided. The determined XRF vehemence’s are converted into flattened standard materials using this technique by splitting each by the required separated amplitude. Some matrix rectifying techniques were developed as an effect of coefficient and intensity estimation techniques using a self-adjustment spectral deviation method. [17]

2.1.2 Laser-induced breakdown spectroscopy (LIBS)

A typical LIBS system contains a pulsed laser, a scanning unit that includes a spectrometer and a detector, an optic system involving a mirror, focusing lens, and optical fibre, and a desktop computer (PC) that is used to monitor instrument settings and analyse results. The LIBS technique analyses the surface of a sample with a laser to determine its elemental makeup. A pulsed Neodymium-doped Yttrium Aluminium Garnet (Nd: YAG) laser is focused with sufficient energy using a focusing lens to produce a spark on the surface of the measured item. The sample's surface gets heated and melts as a consequence of the laser energy absorption. The material's outermost electrons will break the connection by becoming free electrons when they spend enough energy, ionizing the sample. The energetic electrons collide with atoms throughout a collision of excited free electrons, resulting in a cascade ionization of numerous atoms. [18]

A high-temperature laser plasma is formed from many particles, including free electrons, ions, and atoms. Free 1% electrons, ions, and a substantial number of high-energy atoms are included in this plasma. The atoms and ions that are excited they are quickly decayed to the ground state when the laser operation is stopped, resulting in spectral lines of frequencies describing the composition of the elements. In other words, the energy from a LIBS sample excites elemental species present in the resultant sample plume into an amount that can be detected using a sensor, as illustrated in Figure 10.

The vapours absorb and desynchronize with de-excitation and optical absorption on very short time scales. Time-dependent spectroscopy can identify the elements with the spectral peaks. This laser plasma is raised to higher temperatures in order to create radiation, which is then sent to an optical fibre where it is detected using a spectrometer. [18]

The spectrometer, which directs light into the ICCD detector, splits the plasma's white light into its component wavelengths and then transmits them to the detector, which converts the optical signal to an electrical signal. To calculate the elemental composition and quality of the sample under inspection, computer software uses the spectrum (frequency range). [18]

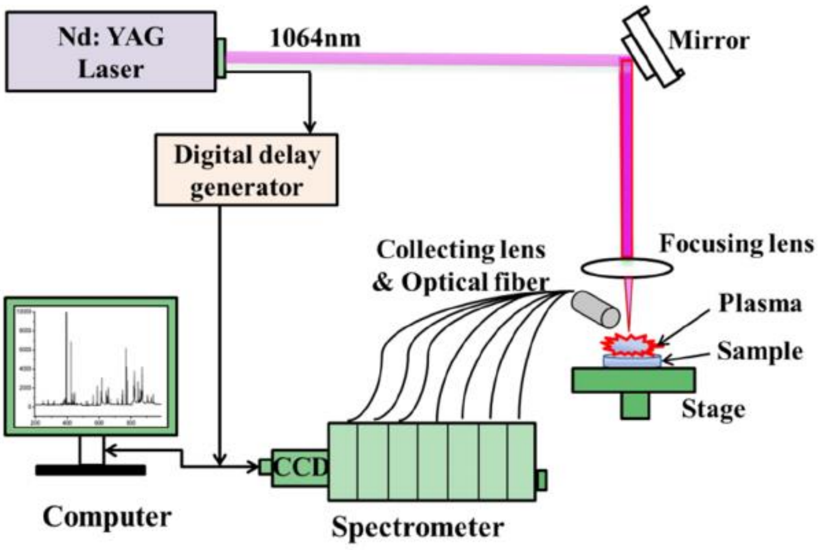

Figure 10. A schematic diagram of a Laser-induced breakdown spectroscopy monitoring system (LIBS) [21].

2.2 Line construction for sorting of impregnated wood

In this section, we discuss about the conveyance system, targeted metals, detection order and the diverting system of the impregnated wood.

2.2.1 Conveyance system

According to Hasan et.al (2011) suggests that the XRF sorting device planned to be located under a wood sorting facility's picking line. Due to the design of the XRF chamber atop the infeed conveyor, wood was restricted to lengths of less than or equivalent to 150 cm, which accommodates most wood pieces accepted at this plant. A schematic diagram of the line construction is displayed below in figure 11.

The infeed motorized belt conveyor is 5 meters long, 54.2 centimetres wide, and 297 centimetres high. A third conveyor (3m long, 108cm wide, and 165cm high) was built perpendicular to the infeed conveyor's discharge end. While the infeed conveyor (0.5 m/s belt speed) receives and carries manually supplied wood to the XRF detection equipment, the outfeed conveyor transfers untreated wood to a separate pile for further processing. [22]

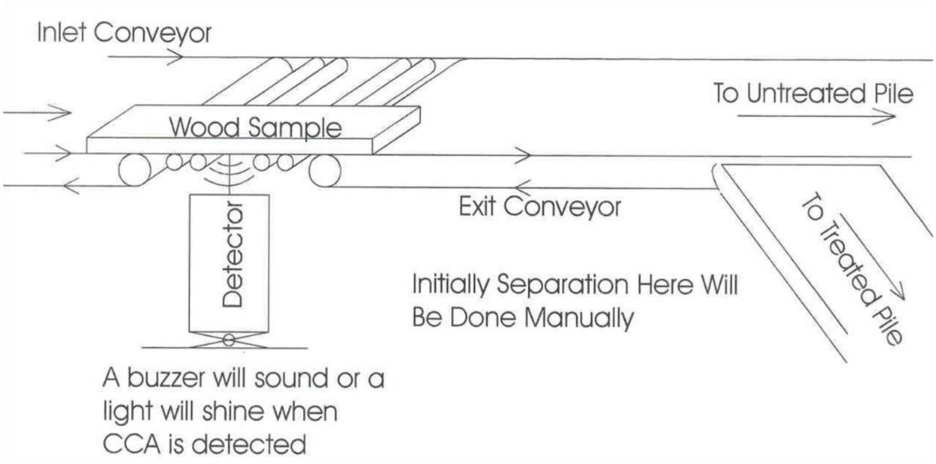

Figure 11. A schematic diagram of line construction in the sorting of CCA treated wood [20].

2.2.2 Targeted metals

(According to Freeman and McIntyre, 2008), Detection of preserved wood using online XRF technologies with an emphasis on the nature of As & Cu in wood. The appearance of Arsenic and Copper in the wood resulted in the identification of arsenical preservatives, most certainly CCA, but also (ACA) including (ACZA). Cu alone signalled the existence of copper-based (non-arsenical) additives such as (ACQ), or the more modern product, (MCQ) .[19]

2.2.3 Detection order

The XRF monitoring device consisted of an X-ray tube with a Rhodium anode (Varian Medical Systems, model VF-50J RH/S-1.0/S operating at 44 kV and 1 mA, placed 40 cm from the belt and releasing an X-ray beam downward while stimulated with a 70^0 cone angle. An aluminium filter was used to modify the beam in order to minimize background emissions from the tube's spectrum radiation. The filter was installed on top of a lead-coated fork-covered blade collimator (3 cm apart), as Pb is an excellent material for dampening X-rays and was used to narrow the beam angle and concentrate the X-rays on the illuminated region, allowing tiny wood fragments to be detected more clearly against the conveyor belt backdrop. [23]

It was positioned at a 450 degree angle from the horizontal and approximately 30 cm above the wood components, allowing inspection from the top down rather than bottom up. The X-ray tube and detector are both enclosed in a steel chamber with just a thin film window for detection[23]. To prevent direct exposure to the X-ray tube's X-rays, a Pb fragment was put on the detector's side facing that tube. The detector is linked to an unique software-controlled digital pulse processor (DPP) device (AAI-UofM, Austin AI, Austin, TX).

2.2.4 Diverting system

Once the samples of wood have been inspected and the remaining chamber inspected, a slide disturber has discharged treated wood from the end of the inlet conveyor (an 81.3x81.30x0.6 cm sheet of steel which was operated in a pneumatic way with a driving piston attached to an air compressor) which is in a suitable position (45 degrees up to the horizon).

Once the desired metal, arsenic or copper, was identified (NCR > OTTM), the diverter was designed to open after a predetermined pause and stay open for a predetermined dwell period. The delay is related to the distance travelled by the wood component on the belt between the inspection point and the conveyor discharge end and is proportional to the belt rpm. A delay time of 1700 milliseconds was selected for this research since it has been shown to efficiently deflect tiny wood fragments (5 cm). The dwell period begins after the pause time and is proportional to the number of the measurement periods at which the target metal is detected consecutively plus a minor amount called pulse adjust (500ms in this study) to account for wood transitioning from the belts to the diverter. [19]

2.3 Current existing technologies in XRF

In the market, there are several methods used in the XRF industry as ED-XRF and WD-XRF are both widely used methods, there is a brief overview of these current technologies discussed in this section starting from their efficiencies, advantages and their disadvantages.

2.3.1 Energy dispersive XRF (EDXRF)

All spectrometers work on the same basic principle: they include a source of radiation, a sample, and a detecting system. An X-ray tube serves as the source and directly irradiates a sample in an EDXRF spectrometer, while an energy dispersive detector detects the fluorescence released by the sample. This detector can detect the signature radiation emitted by the sample at a variety of different energies. The detector will distinguish between the radiation released by the sample and that emitted by the different elements shown in Figure 12 Dispersion is the term used to describe this process of separation. [24]

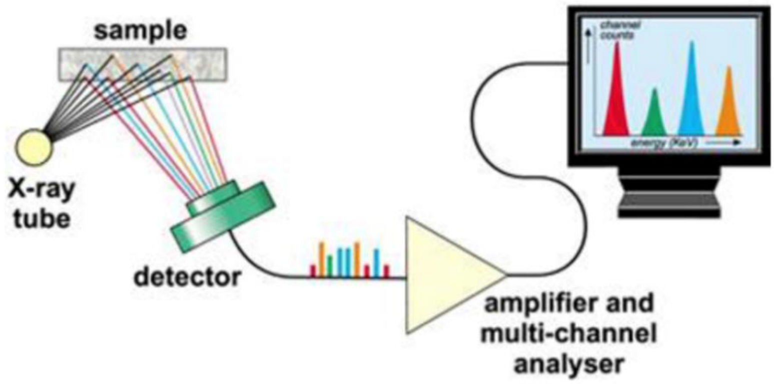

Figure 12. Method of detection using EDXRF [24].

A few advantages of EDXRF spectrometers

1. Instrument in a small, portable form
2. Maintenance is minimal
3. Water, compressed air, or gases are not needed.
4. Electricity demand is very Low
5. Enhanced resolution of the system
6. Analyses of elements conducted concurrently

2.3.2 Wavelength dispersive XRF (WDXRF)

In elemental research, Wavelength Dispersive X-ray Fluorescence (WDXRF) has been one of two X-ray Fluorescence instrumentation methods utilized. WDXRF spectrometers excite both elements in a sample simultaneously. An observing crystal or monochromator diffracts the various energies of the sample's characteristic radiation in many directions, much to how a prism disperses distinct colours of visible light into multiple directions. [25]

The sensitivity of an X-ray wavelength may be determined by orienting the detector at a specific angle. Concurrent spectrometers compute the intensities of a broad range of wavelengths by spinning a detector placed on a goniometer. Simultaneous spectrometers are composed of a succession of stationary detector devices, each of which measures the radiation of a different element. The main advantage of WDXRF systems is their high resolution (often 5–20 eV) and absence of spectrum overlap. [25]

The addition of X-ray optics to WDXRF equipment may improve its performance. For common XRF equipment, effective focal diameters at the sample surface range from several hundred micrometres to several millimetres. Polycapillary focusing optics absorb X-rays from a divergent source and concentrate them into a tightly focused beam with a diameter of a few tens of micrometres at the sample surface. Increased spatial precision and efficiency for trace element estimation in Micro WDXRF applications are enabled by improved sample strength within a tiny focus point. Through a parallel beam, polycapillary collimating optics effectively gather fluorescent X-rays from a tiny area on the sample surface or from energy dispersion on the inspecting flat crystal. [25]

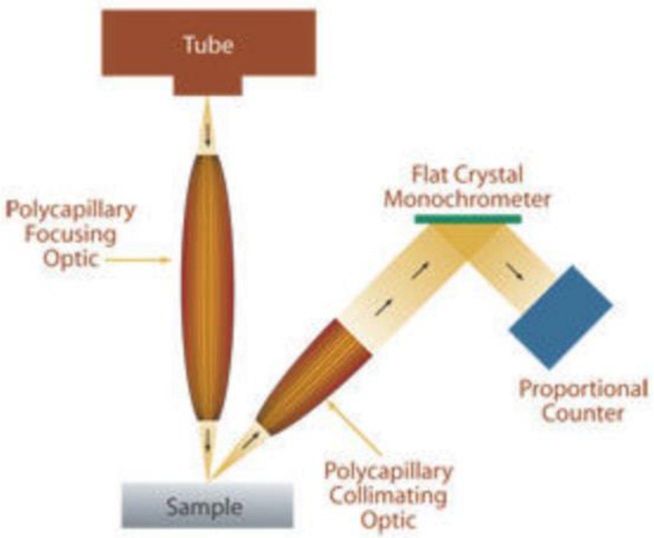

Figure 13. Using a flat crystal monochromator. [25]

Alternatively, rather than capturing and dispersing light using a polycapillary collimating optic and a flat crystal, the doubly curved crystal monochromator may be used to gather and direct chosen emitted fluorescence from the material.

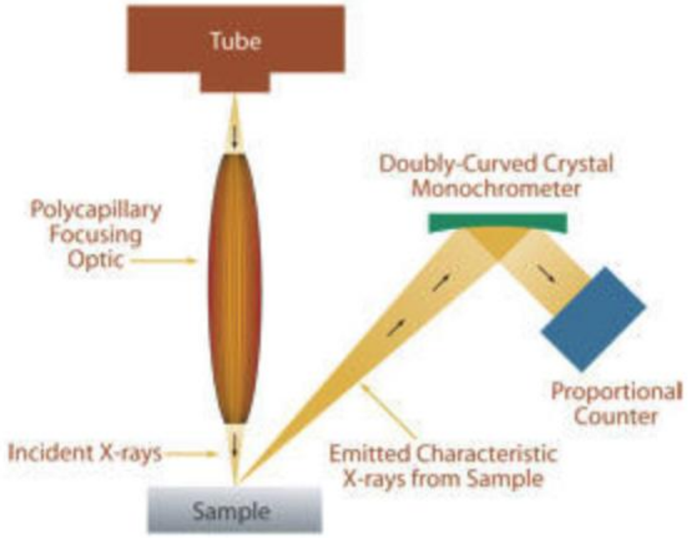

Figure 14. Using a doubly curved crystal monochromator. [25]

Additionally, twin curved crystal lenses may be utilized for monochromatic WDXRF, resulting in extremely high sensitivity for a single sample factor of interest. Using the XOS SINDIE analyser, the method was successfully used for the detection of tiny quantities of sulphur in petroleum.

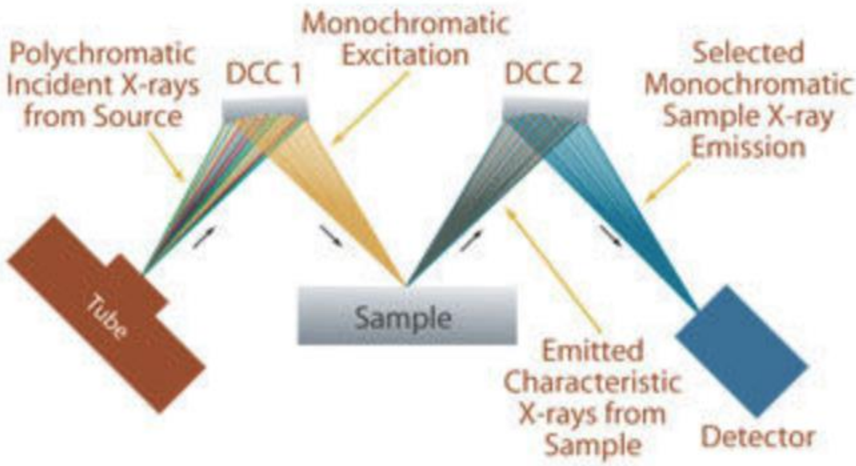

Figure 15. With the use of Double curvy crystal optics. [25]

Aspects of WDXRF spectrometry that are advantageous

1. Excellent resolution, especially for lighter elements
2. Limits of detection are low, especially for lighter elements.
3. Convincing analysis
4. High-throughput operation. [26]

2.3.3 Comparison of EDXRF and WDXRF methods

According to experts from Eastern applied research, EDXRF analysers have witnessed technological advancements that have resulted in the extension of application areas, when compared to the applications addressed by WDXRF.

Both technologies are focused on the concept of excitation of a sample by an x-ray source, collection of fluoresced x-rays by a detector system, and processing of the measurement data by a software program. A wavelength system may be identified by the fact that a crystal between the two tubes diffracts x-rays of a certain wavelength via the detection tube. As a result of this extra step (and component), the technology output capabilities and prices vary. [27]

There are two significant variations between these two techniques that influence their performance: -

Both technologies are focused on the concept of excitation of a sample by an x-ray source, collection of fluoresced x-rays by a detector system, and processing of the measurement data by a software program. A wavelength system is characterized by the fact that a crystal between the two tubes diffracts specific wavelength x-rays via the detection tube. As a result of this extra step and the component, the technologies' output capabilities and prices vary. [27]

<u>Resolution in energy: -</u>

Typically, WDXRF analysers have a resolution range of 5eV to 20eV, while EDXRF analysers have a resolution range of 120eV to 220eV. Due to WDXRF's lower resolution, it is possible to minimize spectral overlaps, allowing for a more efficient categorization of complicated data.

While this distinction enables the development of wavelength technologies for a particular element or application, the optical components needed to achieve such resolutions result in a more costly device both initially and over time. Advances in EDXRF detection systems have considerably increased such resolutions, expanding the number of applications that may be addressed with EDXRF. [27]

Spectral Accretion: -

It is a constraint on wavelength-dispersive technology since a spectrum must be created i.e., extremely time consuming or with external detectors (Expensive approach). On the other side, energy dispersive can acquire the whole spectrum nearly simultaneously. If a user can notice a slight decrease in precision with a single element, the range of items seen is done more quickly and efficiently, resulting in a greater range of substance analysis capabilities.

According to the author, Energy Dispersive XRF has improved tremendously from the previous years, with the addition of poly-capillary optics to rapidly detect the composition of elements in the pressure-treated wood [27].

3 RESEARCH METHODS

In this section, techniques used to assess various characteristics of wood are described. Two majorly used techniques are XRF and LIBS. The methods along with working parameters, basic working principles, and examples from similar research carried out by [29] are presented. Also, a brief comparison between XRF and LIBS is described at the end of this section.

3.1 XRF Technology

According to Hasan et al. (2011), the WD-XRF experiment was performed utilizing a Bruker Instruments S6 Jaguar outfitted with a 400W 17 mA X-ray source equipped with four analyzer crystals. The length of the measurement is inversely related to the Limit of Detection (LOD); it has been set to 15 seconds based on early testing findings. The measurement time has been modified to take into consideration the detection threshold (LOD), which is often lower than the normative limits for most components, the accuracy (S/N ratio), and finally the time spent doing a single measurement. Additionally, the possibility of receiving erroneous positive or negative findings was addressed. [29]

To allow for the potential of the system being used to detect impregnated wood in a sorting facility, the measurement duration was set to a low value. In terms of measurement, the trade-off was acceptable. The LOD values for As, Cu, and Cr are satisfactory (greater than three times normative limits); the LOD values for As, Cu, and Cr were generally satisfactory for monitoring concentrations as low as two to three times normative limits, so they are continued to improve by increasing the test time; the LOD values for Cl and Ti are not suitable for normative limits without a significant increase in scan time. The technical specifications of the XRF machinery are mentioned in the below table 2.

Figure 16. WD-XRF Bruker Instruments S6 Jaguar machine [28].

Table 2. Technical specifications of WD-XRF Bruker Instruments S6 Jaguar [28].

	Specifications	**Benefit**
HighSense X ray power	400W ,50KV Max, 17mA Maximum	Optimal analysis of heavy components and light elements with low kV and high mA at full power.
Specimen sizes	Masked diameter: 34mm is standard Optional additional sample masks: 28mm,23mm,18mm	Maximum intensity and analytical versatility for samples with varying sizes
Prime beam filter	Automated 5-position beam filter changer (optional)	Improved detection limits because of an increased peak to background ratio Tube shield during sample loading.

Analyzing crystals	XS-55 for F -Mg PET for Al – Cl LiF200 for K – U Ge, XS-Ge-C, XS-400, Lif220	Analytical versatility throughout the whole elemental spectrum and improved performance
Detectors	Proportional counter High sense XE FOR Ti - Am	Optimal detection Linear range: 2 Mcps
Suction pump	Included, 265mm x 180mm x 489mm	Low operating costs
Helium purge	(optional)	Liquid analysis
Touch control	Easy to use interface (optional)	Operation that is failsafe and minimizes operator training
Temp control unit	Included, no additional chiller 466mm x 190mm x 630mm	Increased analytical accuracy and improved thermal stability
Power supply	100-240v, 50/60Hz, max. 1kVA	Standard wall outlet
Safety standards	DIN EN ISO 9001:2008 certified German type approval, Radiation < 1μSv/h	

3.2 XRF Sorting of impregnated wood with conveyor system

According to article [29]3., It had an infeed motorized belt conveyor and an inclined conveyor (6m in length, 54.2 cm wide, and 297 mm high) perpendicular to the infeed conveyor's discharge end (3m long, 108 cm wide, and 165cm high). The slanted conveyor sent raw wood to a separate pile for further processing.

On top of the infeed conveyor, the XRF detection equipment was installed. Following assessment, treated wood is released from the bottom of the infeed conveyor through a slide-way diverter, avoiding contact with the incline conveyor (Fig. 17). On the inclined conveyor, steel shields are installed to reduce the impact of wood particles skipping and rolling after being redirected. Once the slide-way diverter is opened, the time required to travel from the assigned region to the conveyor terminal is adjusted to account for wood time. The delay time is related to the belt speed and distance between both the XRF inspection point and the input conveyor's terminus. The focus was on detecting As and Cu in conserved wood using XRF. As and Cu in the wood reveal the presence of CCA, more likely arsenic preservatives. Copper was detected only in the presence of copper-preservatives including such alkaline copper quat (ACQ). [29]

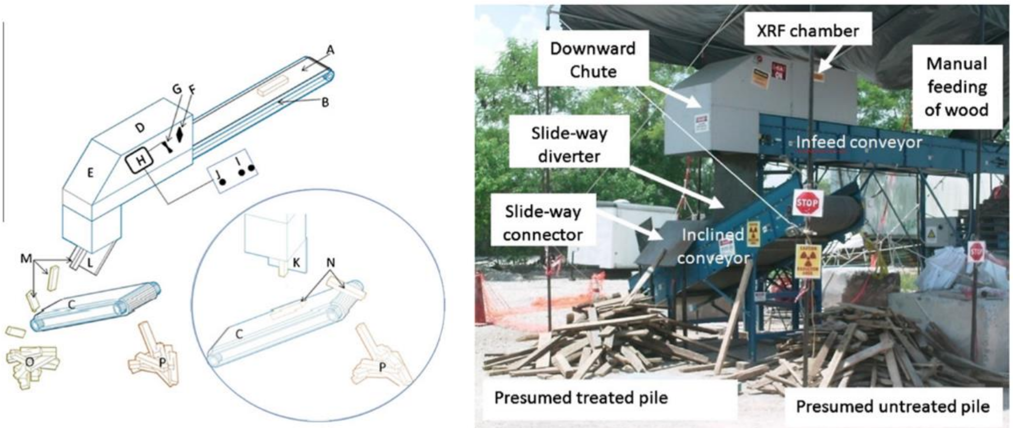

Figure 17. A complete schematic (Left) and Working picture (Right) [29].

3.3 Working parameters

To verify whether the recommended XRF range between impregnated and untreated wood samples and XRF probe head was accurate and impregnated and an untreated wood sample was placed far enough apart to provide enough space for the XRF probe to function properly

Both impregnated wood and untreated wood were evaluated. When the distance between samples grew, arsenic counts dropped. [30]

Some of the variations between impregnated and untreated wood could still be easily seen at 2.5 cm. new and impregnated wood both had values between 70 and 100 counts of arsenic, whereas untreated wood had lower levels. If the retention level of newly impregnated wood is maintained, the readings of the count shall increase. The treated wood showed a higher count than the untreated wood. Since the impregnated chemical was no longer present in the wood when it was in service, the lower counts found in untreated wood are most likely attributable to the impregnated chemical's absence. [30]

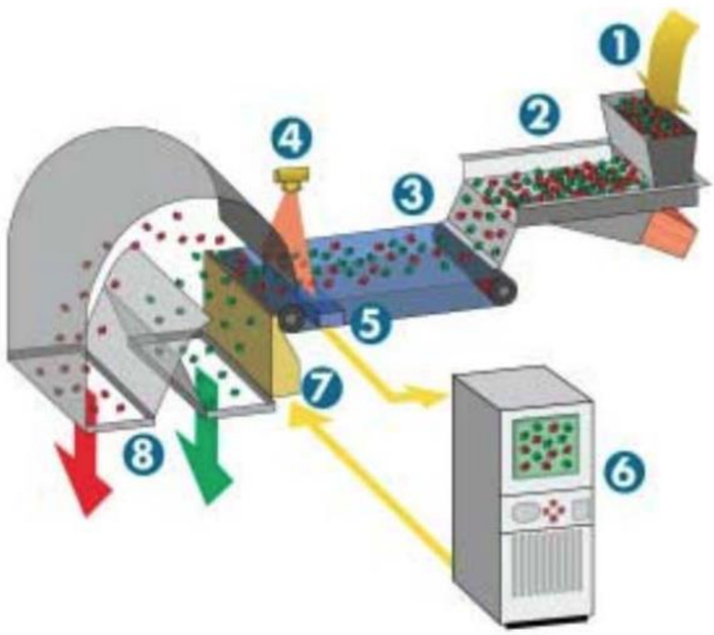

Figure 18. Industrial operation of X-ray sorting [32].

When the XRF head is positioned right on the wood sample, there is a clear distinction between newly impregnated and newly untreated wood, even though arsenic counts consistently show that new impregnated wood does have arsenic counts higher than 1000, whereas new untreated wood has arsenic counts less than 100, regardless of the XRF head's position on the wood sample. Those with an XRF count of less than 100 are considered untreated, whereas samples with an XRF count of 100 to 1,000 are considered uncharacterized. [30]

The shortest possible distance in between the XRF head and the wood samples is calculated while online sorting, but only if the samples are tiny. To determine the threshold at 1.9 cm between impregnated and untreated wood, a collection of 300 randomly selected untreated wood samples were examined. 172 samples were discovered to be untreated, whereas 126 samples discovered to be impregnated at a 0 cm depth (in other words, an untreated sample and an impregnated wood sample were placed a few millimeters apart and observed for quality). [30]

To provide more specificity, a hierarchy of bins for the data was constructed where the values more than 200, between 180 and 199, between 160 and 179, and so on could be placed as a measure was then implemented, where each wood sample was classified according to its arsenic level and the samples within each classification were counted. The distribution of samples was found to be bimodal, indicating that they fell into two distinct groups. [30]

Samples providing arsenic concentrations between 80 and 160 accounted for only six of the 300 samples as shown in Table 3, while the other samples were found to be more than 160. Since four samples with counts between 100 and 160 have likewise not been treated, it is quite probable that they were untreated. The findings assume a normal distribution. Several 60 arsenic counts were subsequently chosen as the 1.9 cm distance threshold. Around a third of the samples were not impregnated for this condition, with 176 of them being the ones we're examining. [30]

The proposed threshold values result in a two-sample difference in the number of samples classified as impregnated between 0 and 1.9 cm. Two samples with a 0.1 cm difference in identification between 0 and 1.9 cm distance were two of four believed to be untreated at 0 cm distance. Two samples had a count density of about 100-140 counts per square centimeter (CPS) at 0cm and approximately 50-55 CPS at 1.9cm. The collection of samples are presented in the below table 3. [30]

Table 3. Effect of distance between the wood impregnated wood sample with given Arsenic and copper count [30].

Limitations of the bin	No. of wooden samples in each bin	
	0cm	1.9cm
> = 200	122	94
180-199	0	6
160-179	0	11
140-159	2	4
120-139	1	4
100-119	1	3
80-99	2	1
60-79	111	1
40-59	61	6
20-39	0	163
0-19	0	7
Sum	300	300

3.4 Evaluation of metals in impregnated wood

The detector was specifically put on the heartwood and sapwood sections of the wood, as well as a nail and many knots, to test whether these features, which are typical while sorting wood, would hinder the XRF system's ability to identify Impregnated wood. Using an XRF probe, the samples were examined directly on the wood surface. The sapwood (1360) wooden component had much more arsenic than the heartwood (1360) wooden component (1300). Arsenic concentrations in knots have also decreased (1240). To determine the presence of knots or the sapwood-to-heartwood ratio, the XRF system regularly produced readings higher than the impregnated wood's 100-count threshold. A screw driven into untreated piece of wood produced somewhat higher As count readings (96 vs 80 counts), but the results remained consistently below the 100-count threshold. [29]

On XRF readings, the impacts of surface coats were identified when covering a fresh part of 6,4 kg/m^3 impregnated wood with oil paint, latex paint, another side of untreated wood. 100

per cent Acrylic Latex semi-gloss, white, external Minwax Water-based Stain, and water with a transparent copper-8-quinolinate wood preservative. The collection of data was made on coated and uncoated sides of each piece of wood, with a period of 3 seconds and 1.9 centimeters long, between the wood specimen and the XRF sensor head. In impregnated wood samples, except for the stain on the water, surface coatings seemed to be lower in arsenic (Figure 16). While the measurements were typically lower for coating purposes, they remained above an impregnated wood threshold of 1,9 cm over the 60-count threshold. So, the XRF system was able to recognize the impregnated sample even when the wood is coated with paint or dye. [30]

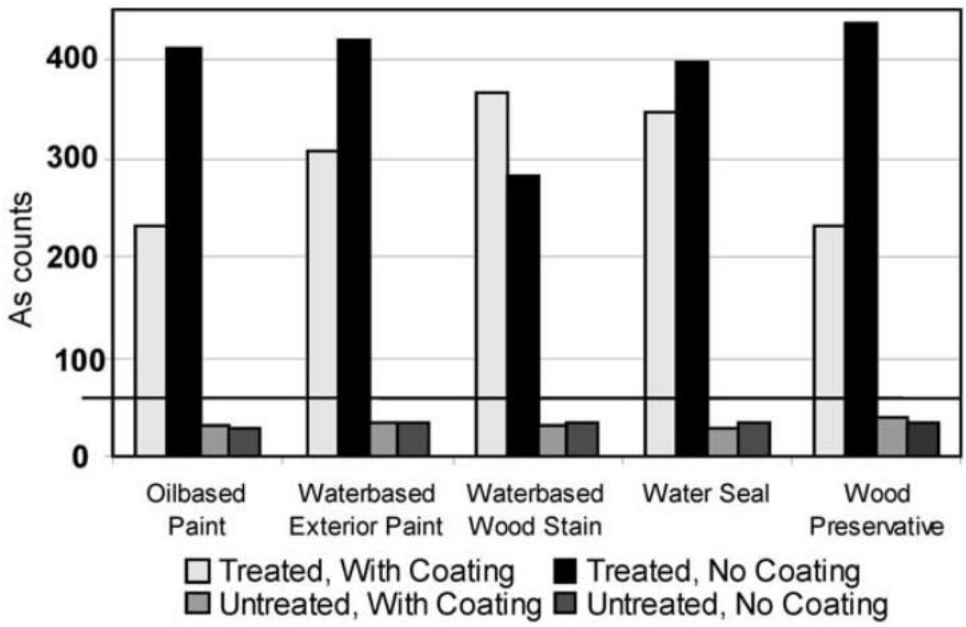

Figure 19. The XRF on arsenic in impregnated and untreated wood has an impact on the surface coats [30].

The distanced variation wet and dry wood is critical because the moisture level of the hardwood logs provided by the provider varies according on prior rainfall conditions and available cover. Thirty minutes later, samples were submerged in water to evaluate the effect using the same XRF method as with the dry samples 1.9 centimeters and 3 second time frame. To ascertain the magnitude of the effect, samples of "surface coverage" were collected. When the difference in arsenic content between wet and dry samples was not statistically significant, XRF can detect impregnated wood regardless of its moisture condition. [31]

Non-arsenic wood samples were examined at 1.9 centimeters between wood and the XRF head with a count time of 3 seconds. The wood that was not treated with arsenic was treated with (ACQ), (CBA), (CC), and (CDDC). Additional information regarding these samples' characteristics is provided. All non-arsenical impregnated wood samples had low arsenic concentrations, less than the 60-count criterion for impregnated wood (Table 4). Additionally, the samples included low in Cr and high in Cu concentrations, which matched the formulas of the alternative compounds. [31]

Table 4: Capability of XRF for As, Cr and Cu detection in CCA, CDDC, ACQ, CC OR CBA untreated wood and impregnated wood [30].

Treatment method	As	Cr	Cu
Untreated	33	17	22
Impregnated	493	121	251
CDDC	33	37	486
ACQ	31	39	501
CBA	36	27	326

3.5 LIBS technology used for this research

The LIBS technology used for this research is ARYELLE 400 from (Laser Technik Berlin) it's a flagship device and the most reliable device the company could offer ARYELLE echelle spectrometer line, with extremely high spectral resolution in the VUV or UV-VIS-NIR wide-range and a focal length of 400 mm – ideal for accurate elemental analysis using LIBS and Raman spectroscopy.

1. Highly sensitive and stable in wavelength
2. High-resolution spectral analysis (9,000-50,000)
3. Broad simultaneity of wavelengths
4. Compatible with a variety of detectors (CCD, ICCD)
5. Increased light output

The ARYELLE 400 boasts the greatest spectral resolution of the Array echelle series, a focal length of 400mm with an aperture of f/10. The proprietary optical system, which includes an echelle grating, a prism, imaging optics, and an entry slit, can be customized for specific client applications. The ARYELLE 400 can measure two-dimensional echelle spectra depending on the concurrently detectable wavelength range necessary. With a conventional spectrometer design with a 50 m entry slit, spectral resolving powers of up to 30,000 may be reached as in the VUV range (175-330 nm) and up to 15,000 in the UV-VIS-NIR range (330-850 nm). The opto-mechanical system is configured to accommodate a variety of CCD and ICCD cameras. A mercury light and an inbuilt shutter offer automatic wavelength scale calibration, As seen in table 5 and 6. [33]

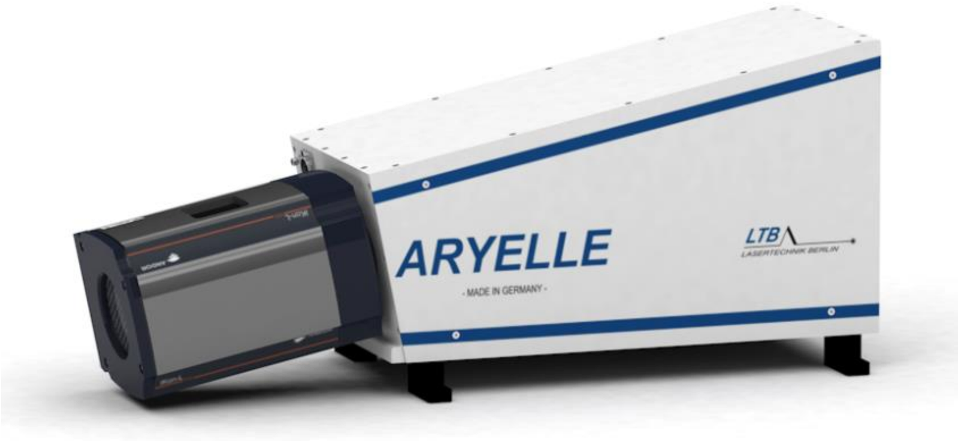

Figure 20. ARYELLE 400 LIBS System [33].

Table 5. Specifications of ARYELLE 400 [33].

Optical design	Echelle spectrograph
Aperture	f/10
Focal length	400mm
Slit width	50µm
Accuracy	Spectral resolution / 4
Dynamic range	15bit, A/D conversion 16bit
Light coupling	SMA fiber coupling or mirror optics
Wavelength calibration	With mercury lamp

Operating software	PC incl. TFT or laptop with Microsoft Windows
Software	Sophi, LabVIEW library optional
Dimensions without detector (L x W x H)	(438x200x232) mm
Weight without detector	12kg

Table 6. Technical specifications of ARYELLE 400 [33].

SETUP	1	2	3	4	5	6
Detector	CCD	CCD	CCD	CCD	ICCD	ICCD
Wavelength	190-330nm	330-850nm	192-930nm	250-900nm	192-433nm	425-750nm
Spectral resolving power λ/min. measurable FWHM	30,000	15,000	15,000	45,000	14,000	20,000
Spectral resolution	6-11pm	22-57pm	13-62pm	5.6-20pm	13-31pm	21-37pm
Detector resolution	2,048 x 512 px	2,048 x 512 px	2,048 x 2,048 px	2,048 x 2,048 px	1,024 x 1,024 px	1,024 x 1,024 px
Image area	27.6 x 6.9 mm2	27.6 x 6.9 mm2	27.6 x 27.6 mm2	27.6 x 27.6 mm2	13.3 x 13.3 mm2	13.3 x 13.3 mm2
Chopper	yes	yes	yes	yes	no	no
Step width, min	0.1µs	0.1µs	0.1µs	0.1µs	0.1µs	0.1µs
Gate width	-	-	-	-	5ns	5ns

3.6 Working parameters and sorting of wood with conveyor system

The LIBS system was constructed using a Q-switched Nd: YAG laser operating at 1064 nm with an eight-ns pulse width, a two hertz repetition rate, and a 200mJ pulse energy. The beam deviated by 4.1mm rad, and the near-field beam was 5.8 mm in diameter. Vertically diverting the laser beam downward using a dielectric mirror, and then focusing it with a plano-convex lens with a diameter of 50 mm and a focal length of 200 mm covered with anti-reflection material at 1064 nm. [32]

XRF head is directly positioned on the wood sample, there is indeed a sharp distinction with both newly impregnated and untreated wood because arsenic counts clearly demonstrate that new impregnated wood has As counts greater than 1000 at its lowest retention level (4 kg/m3), whereas fresh untreated wood does have arsenic gets counted below 100, irrespective of the XRF head's position on the wood sample. Them with an XRF count of less than 100 are considered untreated, whereas samples with an XRF count of 100 to 1,000 are considered uncharacterized. [32]

Figure 21. A detailed representation of wood sorting (Right) with an industrial sorting line (left) used in a coal manufacturing facility [32].

The advantage of axial accumulation is that regardless of how far away the plasma breakdown occurs from the focusing lenses, the spectrum emission is captured by the focusing lens. When a specimen surface is not aligned with the focal point, however, the plasma emission projected on the fiber optic gets defocused, that results in less plasma emission being collected. [34]

Despite the laser-induced plasma remaining intense through a much wider range of sample positions relative to the focal point, early findings procured with associated 200mm focusing lenses, plasma compilation, and focused on the optic fiber demonstrated a spatial limit of detection of less than 50 mm. The disadvantage of utilizing a 200-mm lens to connect the gathered emissions to the fiber is that defocusing occurs considerably faster if the plasma does not form at the primary focal point. Pairing the two lenses is a common technique for improving plasma emission collection at fixed sample locations. [34]

However, in today's online sorting systems, wood samples often shift relative to the precise focal point as their thickness changes, resulting in somewhat defocused plasma emission. The larger spot created by the 250 mm focal length lens allowed for more precise detection of plasma emission over a wider range of wood diameters. The most recent design change was designed to enhance plasma emission collecting substantially. When the sample is properly positioned exactly at the laser focal point, plasma emission accretion is maximized, mainly because the optimal plasma volume is generated, and the emission is suitably targeted on the fiber optic. The fiber optic cable was positioned parallel to a focal point of the 250 mm depth of field lenses to concentrate the plasma emissions onto the fiber when the wooden sample was approximately 50 mm well above the laser focus area. This approach effectively balanced the conflicting effects of reduced plasma emission produced by raising the sample above the laser point of focus and enhanced emission collecting due to emissions being optimally focused onto the optic fiber. [34]

The fiber optics carried plasma emission to a tiny integrated spectrometer and an unamplified charge-coupled device sensor array. In terms of spectral range, the spectrometer covered 325–452 nm with an optical dispersion of 0.06 nm per pixel. The spectrometer detected the chromium(I) atomic emission at 425.40, 427.50, and 428.90 nm. [34]

To enhance the overall chromium atomic emission signal, we used spectrometer integration and temporal optimization to synchronize the laser-induced plasma process. This was achieved by activating a single digital delay generator with a TTL output pulse that corresponded to the flashing of a laser flashlight. The laser pulse was emitted 41.3 milliseconds after flashbulb was triggered. [34]

For detector integration, a TTL pulse was produced, but with a delay to maximize the chromium atomic emission signal. Optimal temporal integration occurred within a few microseconds after plasma start. This system was developed with a 17-millisecond delay between the external TTL trigger and signal integration. [34]

To ensure proper temporal integration with entering laser pulse, the delay produced by the delay generator was increased by 17 milliseconds. For all experiments, the CCD's total integration width was set to approximately 5 ms, the minimum integration time achievable. Due to the lack of substantial background light throughout this integration time, no signal was seen inside the absence of plasma emission. [34]

Once impregnated wood is found, the final design incorporated the activation of an appropriate output signal to warn system operators. The software was written in LabView to examine numerous emission data in real-time. The next sections address the specifics of detecting and analyzing plasma emission signals. Whenever the chromium emission signal surpassed a pre - determined level, a PCMCIA digital output card is configured to generate a 2 ms 5V TTL pulse. A tiny array of strobe lights positioned close to LIBS system was triggered by this output pulse. The ensuing strobe flashes served as an easily apparent real-time indicator of the presence of impregnated wood. [34]

3.7 Tests performed with LIBS system

In accordance with Solo-Gabriele, H., Townsend, T., Hahn, D., Moskal, T., Hosein, N., Jambeck, J. and Jacobi, G., (2004) the LIBS equipment, that was designed for this investigation, was unable to identify chemicals on coated samples using the ten-shot analysis. However, one noteworthy result of this investigation would be that the system recognized coated surfaces, even transparent coatings that are invisible to the naked eye. By monitoring both chromium and calcium emission peaks, The LIBS system identifies the presence of Chemicals. The calcium emissions peak is used to identify wood, whereas the chromium emission peak is utilized to identify chemicals inside the wood. [30]

However, when chromium and copper peaks were suppressed during the analysis of the surface coatings, the LIBS technique was able to detect adhesives regardless of their visibility. This may be advantageous for differentiating coated wood items, particularly when contaminants like lead paint may be present. Additional experiments were performed to establish if the LIBS system could burn through the coating, revealing the exposed wood to LIBS analysis. [30]

To burn through the paint, between ten and twenty-five rounds were needed. The LIBS method determined if the wood had been impregnated after it was exposed. Additionally, the LIBS system is evaluated with used wood that had been soaked in the water for 30 minutes. While the laser detected wet wood properly, the LIBS detector could not detect impregnated wood after soaking. Additionally, to assess the XRF system, studies were performed on wood impregnated with ACQ, CBA, CC, and CDDC. The only impregnated wood other than arsenical that tested positive for chromium was CBA-impregnated wood, which was therefore mislabeled as impregnated wood. However, it is unclear why CBA-impregnated wood failed testing. [30]

As seen in Figure 22, LIBS technology could clearly identify chromium in wood chips.

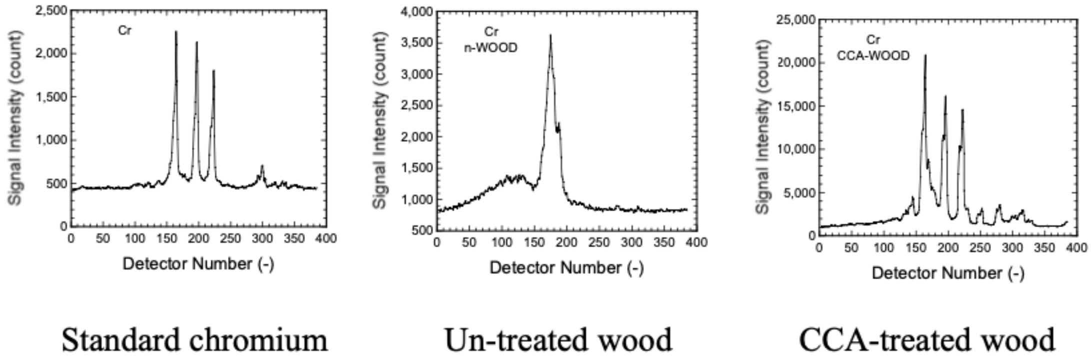

Figure 22. Analysis of chromium detected in wood chips with LIBS Technology

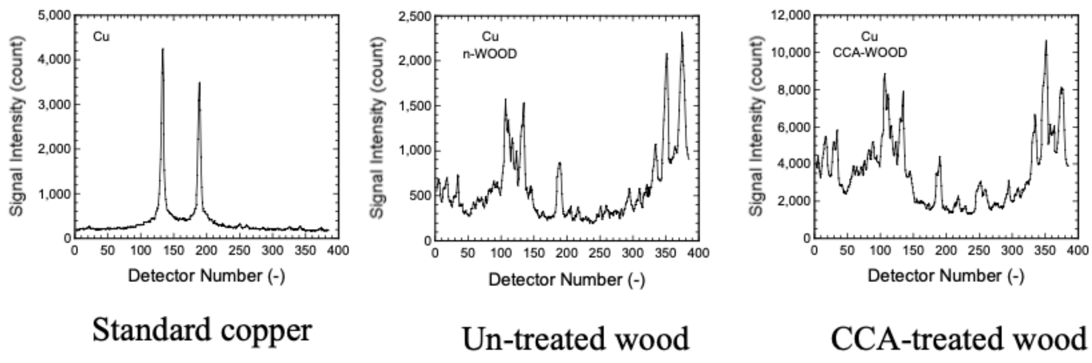

Figure 23. Analysis of copper detected in wood chips with LIBS Technology [35].

As seen in Figures 23 and 24, Arsenic in wood chips have been also recognized using LIBS but would not be as easily recognized as chromium. In the instance of copper, these were established that identifying copper in wood chips was very difficult since copper was utilized as just a preservative in a variety of types of wood in Japan. [35]

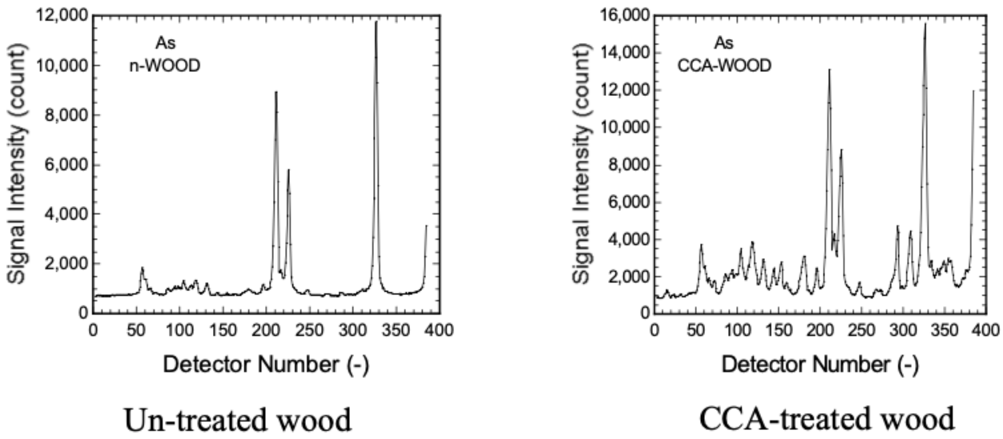

Figure 24. Analysis of Arsenic detected wood chips with LIBS technology [35].

Table 7. Additionally, no other preservative containing chromium exists except in Impregnated wood. As a result, chromium was chosen as the best predictor of impregnated wood content in samples.

	Metal concentrations ranging in impregnated wood (mg/kg-wood)	
Cr	212	5,980
Cu	79	2,750
As	62	2,670

4 RESULTS AND DISCUSSION

In this part, the examination of types of machinery, conveyance systems, and their benefits has been carried out. We will also discuss cost evaluations with provided market research, and extract capital and operating expenses from pertinent references.

4.1 Wood crushing machinery

After several considerations and market research, we have opted to go with The WEIMA Woodwolf is a one-of-a-kind machine that functions as a pre-crusher. It may operate alone or as part of a two-stage process that also includes a WLK shredder. A screw with a diameter of 600 mm smashes the input material (pallets, large chipboard, or crates.) The Woodwolf can be mounted above a single-shaft shredder, allowing shattered pieces to fall straight into the secondary shredder hopper.

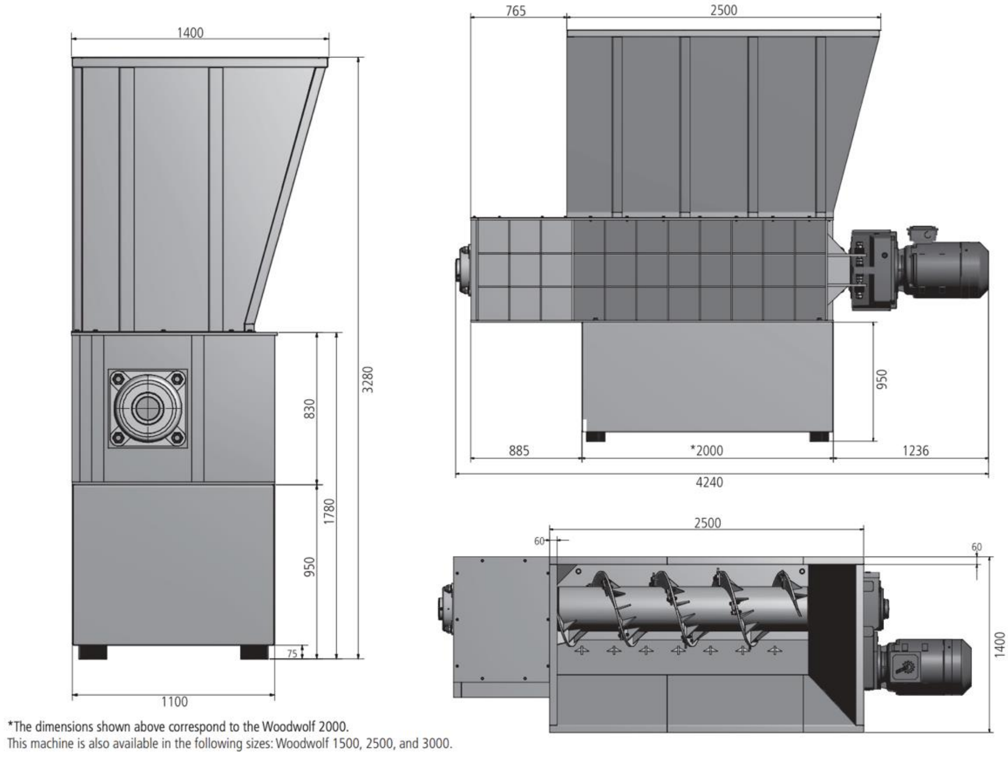

Figure 25. An image of Woodwolf’s wood crusher [45].

The Woodwolf's advantages include the following:

- Huge hopper
- Low revolutions per minute
- Ideally suited as a pre-crusher for large wood waste
- Tooling for crushing that is interchangeable
- Sturdy construction with reinforced steel walls of 40 mm. [45]

4.2 Belt and screw conveyance systems

When it comes to this wood manufacturing line, efficient and effective bulk wooden material handling is essential, as it frequently means the difference between a smooth operation with minimum downtime and a continuous state of upset. We are searching for the most appropriate conveyor systems in this thesis project. Belt conveyors and screw conveyors are examples of such devices. Furthermore, although screw conveyors are a cost-effective solution for many applications, they are not appropriate for all of them. It is critical to grasp the main distinctions between these two kinds of handling equipment when deciding which is the greatest match for the task at hand, as well as the situations in which belt conveyors are the superior handling choice. [40]

4.2.1 Belt conveyance system

The belt conveyor is the first kind of conveyor that we examined. Belt conveyors' biggest benefits are in distance and the ability to transport material across long distances, such as from the outlet and pits to processing plants. Belt conveyors also offer the benefit of having a high-capacity rating, which is another advantage. Essentially, this implies that they can manage a large amount of material at a quicker rate. [40]

Nevertheless, since the belt conveyor only utilizes 19-24 per cent of the available physical area to move material, it would need to be very big in order to transport tons of material. As in figure 26. If you are transporting material that is dangerous, dusty, or explosive, you will need to install external dust control devices, which is another drawback of using this kind of conveyor for bulk material handling applications let’s discuss more information in the upcoming sections. [40]

Figure 26. A perpetual presentation of a belt conveyor system from a sawmill industry [41].

4.2.2 Screw conveyor system

The screw conveyor is the second kind of conveyor available. When it comes to bulk material handling, the screw conveyor is the most often used kind of conveyor by far. There are several reasons for this, including its ability to handle a broad variety of materials, its easy operation, and the relatively cheap cost of acquisition when compared to other conveying systems. When using a screw conveyor, you will have fewer external equipment requirements than when using a belt conveyor. Dusting and contamination will be reduced as a result of this. [40]

Another disadvantage of this type of screw conveyor is the number of horsepower required to run it, which may be very considerable owing towards the material and density. Another disadvantage of this mode of transport is the potential of material degradation during operation. As shown in figure 27, Because screw conveyors do not allow for the preservation of product characteristics during material transfer, they are not recommended. According to FML's study, the screw conveyor deteriorated the material being carried by 6%. [40]

Figure 27. A Canadian custom-built helical screw roller conveyor system [42].

4.2.3 Advantages of belt conveyors over screw conveyors

Belt conveyors are the industry standard for material movement for a reason; they provide several advantages in bulk wood material handling systems. When belt conveyors and screw conveyors are compared, the optimum match is not always obvious, which leads many consumers to choose the less expensive screw conveyor. They often find, though, that a belt conveyor is a much better fit for the task. [43]

There are many instances when a belt conveyor is a superior handling option:

When degradation of materials is a priority -

Belt conveyors provide for delicate handling of wood with minimal material degradation; once the material is put onto the belt, it is confined in the trough, resulting in minimal agitation between the time of loading and the time of discharge. As a result, friable or delicate materials remain intact, and the material or product reaches its destination in the same state for which it was designed. Screw conveyors, on the other hand, employ a helical screw within a trough or tubes to move material forward via connection with the blades, resulting in some friction and, as a result, deterioration of the material. Therefore, they are unsuitable for materials that need delicate handling and where friability is an issue, such as impregnated wood. [43]

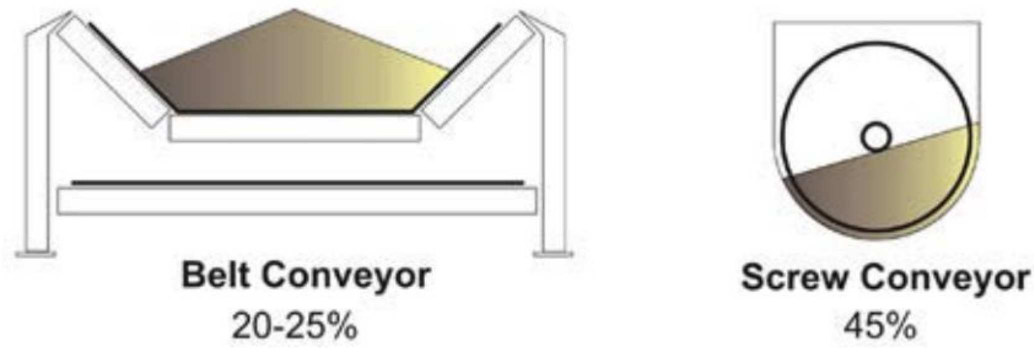

Figure 28. An illustrated comparison of belt conveyor and screw conveyor showing the efficient use of available space. [40]

When managing high throughput applications -

Belt conveyors are capable of transporting material at rates of up to 7,900 tons per hour (TPH). This is much greater than the capabilities of screw conveyors. As a result, they are the ideal option for any high-capacity environment. Belt conveyors are available in widths up to 75 inches and may run at speeds up to 650 feet per minute (FPM).

When working with difficult materials -

The use of belt conveyors and screw conveyors for the transportation of a broad variety of wood products is common. Long and stringy materials, on the other hand, are not well suited for screw conveyors, which are prone to becoming tangled and causing obstructions because of a horizontal screw movement that occurs during the conveying process. The following are examples of materials that usually do not work well with a screw conveyor:

1. Chips of wood
2. Residues from forest products
3. Solid wood wastes

When desiring to reduce energy costs -

Screw conveyors need more horsepower than belt conveyors due to the torque required to move items by force, particularly if they'll be operating on an incline.

When transporting at an angle, belt conveyors offer an advantage over screw conveyors, as they are more effective at conveying at an angle. This is since certain material within screw conveyor starts to tumble backward over blades. [43]

Vertical screw conveyors are one possibility, although their efficiency diminishes with increasing inclination. As a result, high incline conveyors are more effective in situations when the angle of inclination is severe. Additionally, steep incline conveyors may integrate lateral and vertical conveyance into a single device.

While transporting long distances -

Perhaps the most significant benefit of a belt conveyor is its ability to transport materials across short and large distances. A single belt conveyor can transport goods across lengths ranging from 11' to 1600'. Screw conveyors are usually restricted to considerably shorter lengths - about 35m at most.

Applications when working with abrasive materials -

Additionally, belt conveyors are a superior choice when handling abrasive materials. In contrast to a belt conveyor, where the material does not move over the carrying surface, the friction created by a screw conveyor increases abrasive wear just on the unit. Additionally, although screw conveyors may be equipped using abrasion-resistant liner, belt conveyors need less protection against abrasive materials, with additional protection required at discharging hoppers and skirt-boards.

Times when cleanliness and accessibility are essential -

In general, belt conveyors need less cleaning than screw conveyors. Their open design facilitates access and use of belt cleansers typically suffices to meet cleaning needs.

Screw conveyors, on the other hand, do not self-clean and, since they are enclosed, must be stopped down and disassembled in order to completely clean the troughs and shaft. This is particularly troublesome when dealing with moist and/or sticky materials, which tend to cake and accumulate, necessitating more frequent cleaning.

When it is not possible to pack material -

Screw conveyors have the potential to compact material as it travels through the device. This may result in accumulation, obstructions, and even the dislodging and discharge of packed debris. Such issues often result in higher unsettled circumstances requiring time for maintenance and cleaning, as well as extra filtering or condition of the material and uneven product size. Screw conveyors, on the other hand, are usually unsuitable for materials that pack easily, such as clay particles and composts. [43]

Over the past 15 years, several sorting or separation techniques for wood have been developed, including magnitude separation, magnetic field segregation and sensor based segregation. Size separation/reduction is critical for pre-validation even before the sorting process, and it should not be overlooked as mentioned in table 8. The use of automation methods into the wood sorting process has enhanced the effectiveness of sorting systems while also improving the quality, uniformity, and safety of the wood sorting process in general. The automated sorting approaches for sorting may be roughly classified into three categories, depending on the level at which automation is implemented. [36]

Table 8. Belt and Screw Conveyor technology comparison chart [44].

Conveyor type	Belt conveyor	Screw conveyor
Effective utilization of space	Neither effective nor successful	Effective to a degree
Maintenance	High	Nominal
Safe / Dust containment	No	Yes
Cost of ownership in total	Depends on the length of the plant	Depends on the plant capacity
Analysis	A good choice for transporting a large amount of wood material over long distances.	The optimal conveyor for transporting non-friable material over short distances.

4.3 Cost assessment of conveyors and the laser machinery

In this section, the cost assessment and estimation for the conveyor system and the sorting technologies is elaborated. The mechanical costing, capital expenditure and the operational expenditure are calculated according to the current market survey.

4.3.1 CAPEX and OPEX of Belt conveyors

This is an estimate of the transportation system's approximate capital costs made in line with the criteria of the AACEI (American Association of International Cost Engineers) estimation technique in order to reach the agreed accuracy range.[44] The capital cost estimate comprises direct costs such as mechanical components, structural components, and civil costs, among others. Indirect costs include those associated with engineering, labour, freight, and contingency. Generally, the owner's costs, like licenses and land purchase, are separate, although they may be included as well. [44]

In this paper [54] method to calculate cost estimation had been described. to gain cost estimation using this method I tried to search for costs related to this machinery and setup. But data related to costs was not found. so capital and operational cost for this machinery is gained from a source indulged in mining business where similar machinery is used. Mentioned in the below tables 9, 10 and 11.

Table 9. Mechanical parameters of belt conveyor system [46].

Mechanical parameters	Values
Performance	120 t/h
Conveyor length	35m
Belt speed	1.3m/s
Belt width	0.9m
Belt type	Thermoplastic Polyurethane (-30^{0} C)
Step of roller suspensions	1.5m
Mass of roller suspension	8kg
Linear section length	3m

Table 10. Direct cost breakdown is calculated considering the above mechanical values of the conveyor system [47].

Description (Direct costs)	Total Cost (€)
Mechanical	9000
Structural	6000
Concrete	4000
CAD & Engineering	3000
Electrical	3000
Total	25000

Operating expenditure (OPEX) was calculated using the AACEI technique and assumes of an owner-operator. The Operational expenditure cost analysis covers the following:

- Consumption of energy
- Planning and oversight
- Cleaning and upkeep
- Lubrication and inspections
- Equipment maintenance and repairs that have been scheduled
- Equipment maintenance and repairs that occur unexpectedly. [44]

Table 11. OPEX cost breakdown of the conveyor system [44].

OPEX components	OPEX cost (€1K/Annual)
Power consumption	0.73
Supervisor and housekeepers	0.12
Cleaning and house keeping	0.045
Testing, Inspection and Lubrication	0.073
Breakdown activities	0.036
Conveyor belt	0.14
Conveyor Drives, Idler's and Pulleys	0.11
Wear replacement items	0.097
OPEX TOTAL	1.351

Maintenance expenses are determined by the following:

1. OEM maintenance procedures and software
2. Prices of major components of equipment
3. Industry knowledge and experience

4.3.2 CAPEX and OPEX of Screw conveyors

In this paper method to calculate cost estimation had been described. to gain cost estimation using this method I tried to search for costs related to this machinery and setup. But data related to costs was not found. so capital and operational cost for this machinery is gained from a source indulged in mining business where similar machinery is used. A description of mechanical parameters is in Table 12, 13 and 14.

Table 12. Mechanical parameters of screw conveyor system [48].

Mechanical parameters	Values
Drive power	5.5kW, 11.4A, 400V, 50Hz
Length of the conveyor bed	5000mm
Screw diameter	500mm
Length of the screw box	6900mm

Table 13. The CAPEX cost breakdown is calculated considering the above mechanical values of the Screw conveyor system [44].

Description (Direct costs)	Total Cost (€)
Mechanical	15000
Structural	8000
Concrete	6000
Civil Earthworks	10000
Electrical	4000
Total direct costs	€43000

Table 14. OPEX cost breakdown of conveyor system [44].

OPEX components	OPEX Cost (€1K/Annual)
Power consumption	0.84
Supervisor and housekeepers	0.14
Cleaning and house keeping	0.089
Testing, Inspection and Lubrication	0.90
Breakdown activities	0.056
Conveyor Drives, Idler's and Pulleys	0.70
Wear replacement items	0.098
OPEX TOTAL	2.823

- Consumption of energy
- Planning and oversight
- Cleaning and upkeep
- Lubrication and inspections
- Equipment maintenance and repairs that have been scheduled
- Equipment maintenance and repairs that occur unexpectedly.

These costs are adjusted according to current inflation and are calculated as per approx. market values.

4.3.3 LIBS Costing

The ARYELLE 400 equipment at laser Technik berlin incurred about €55000 in operational equipment expenses throughout its lifetime. A glove box, enclosed frames, shock absorbers, and an aircon are examples of application-specific requirements that may be included in the equipment costs for a new application, the system can function outdoors in extreme temperatures i.e., (4 - 60°C) In comparison to the full suite of auxiliary instrumentation employed from laser Technik berlin, the reduced auxiliary instrumentation suite will be more expensive. The exact cost will be determined by the site's needs. [37]

Approximately €12,75 per hour was projected to be the cost of deployment labour, which was a rate that was paid by the host facility for the services. It is possible that only minor facility modifications and user interface efforts will be needed if the application involves the installation of a stand-alone system in a vast new work area, for example. When installing the ARYELLE 400 in an already operating hot cell facility, however, substantial instrument system design (to accommodate free capacity and/or config needs), facilities and modifications, and installation costs must all be taken into consideration. An estimate of the yearly maintenance costs for the equipment was made at €2600 per unit per year. Unless otherwise stated, all expenditures are in line for the year 2021. Budget estimates did not take into consideration the expenses of transporting wood logs to the job site.[37] This system comes with firmware that enables operation from every remote computer over the Internet, whether via the use of an application including VNC VIEWER or PC Wherever or using browser services such as LogMeIn.

4.3.4 XRF Costing

The functioning of XRF units involves the placing of instrument detectors against the wood log surface should be examined, followed by the compression of the instrument's trigger, which initiates the analysis. A total of 5s was allotted for this study's analysis time. Of note is that, while the analysis time is just 5 seconds, the amount of time required to assess each block of wood is much longer since the wood must be removed, evaluated, and then put in the appropriate pile. The Bruker Instruments S6 Jaguar XRF unit had a suggested retail price of €70,000 i.e., with computer logic with an online detection system.

The annual maintenance cost for the equipment was estimated to be €2100 per unit. To convert the purchase price of the XRF units to per-metric-ton expenses, the instruments' annual use was predicted to be 2200 hours, and the time required to sort impregnated wood loads using XRF was calculated to be 8.4 hours per metric ton. Labour expenses were calculated at €12,75 per hour, with the host facility covering the cost of the services. Consequently, the disposal price for a woodpile comprising 7 per cent treated wood was estimated at € 4.3 per ton, which included direct pay as well as workman's compensation expenses. All expenses are in accordance with the year 2021. The costs involved with transporting the wood logs to the worksite were not included in budget calculations. [37]

4.3.5 Overall comparison of XRF and LIBS

When it comes to chemical analysis outside of the laboratory, XRF is the primary rival of LIBS. Of course, each method has benefits and drawbacks that are unique to the instrument in question. The XRF devices, which are commercially accessible for a longer period, are technologically very mature. The fact that the fluorescence yield drops dramatically with lowering atomic numbers means they should inherent physical limits for measuring elements with low atomic numbers, which are usually Si or insubstantial elements.

The XRF method, as previously mentioned, is unable to differentiate between the elements magnesium and nitrate with great precision with absorption of intense X-rays by air. To enhance overall degree of detail for these lightweight components, utilize vacuum cleaner or Helium gas purge (options that are often provided as extras by the instrument maker). Aside from that, the most recent commercially available XRF devices have been outfitted with graphene windows, both are stronger and significantly thinner than the previously used Beryllium window foils, allowing for improved detection of Cu, As, and Cr compared with the previous generation of devices.

Although, XRF is a more established quantitative technique than LIBS, it is constrained by licensing requirements, particular op precautions, and training safety for staff owing to the open beam X-ray source, which restrict shipping. Furthermore, key XRF analyser components such as tubes and detectors, particularly SSDs, are costly. While the price of the detectors varies from the manufacturer and their instrument features, both types of systems are extremely affordable, usually ranging in the hundreds of euros.

LIBS is considerably faster than XRF in identifying elements in real-time. While LIBS can potentially identify all elements in the periodic table, it is specially well suited to detect light elements such as Hydrogen, Lithium, Beryllium, Boron, Carbon, Nitrogen, and Oxygen, this task cannot be performed by energy dispersive method. Both of the detection techniques should give reliable quantitative results.

Because the LIBS instrument doesn't produce ionizing radiation, it would not require the distinctive requirements for the operation as the XRF equipment does. To solve laser safety concerns for LIBS instruments, locking mechanism is used, which ensures that until the unit is in touch with a wooden sample, the laser will not fire. An ordinary characteristic of the current generation of commercial LIBS analysers is their ability to do spectral analysis. [38]

Additionally, the way wood samples are processed and the geographic scope of the region being analysed are critical variables to consider when comparing the two methods. Because XRF is a surface method, some contact cleaning and preparation may be necessary at times, whereas LIBS utilizes the initial laser pulses to effectively ablate and cleanse the sample surface prior to analysis. The focal length for analysis on an XRF device is usually few millimetres in diameter, whereas a single LIBS shot should cover an area about 50–600 meters in diameter, culminating in a spatial resolution much greater than that of XRF technology. Apart from that, LIBS is often used to gather representative data through a restoring capability that also enables compositional mapping on a local geographical scale.

As a result, by changing the way a LIBS spectrum is built, it is possible to include several distinct lines in the ultraviolet rays, visual infrared spectrum, or near infrared rays areas with elements are presented in the samples, depending on their composition. As a consequence, it is possible to investigate a particular emission line whilst ignoring or reducing involvement from other spectral lines. The XRF spectrum, on the other hand is extremely basic, with just two to five images specified per element. [38]

Because there are no alternative lines, it is difficult to avoid potential interferences that seem to be common in matrices. As a result, proper deconvoluting spectral overlaps methods must be used. LIBS, on the other hand, need a device for dispersing the produced light into various wavelengths, while XRF, particularly energy dispersive method, should not require any additional equipment between both the sample and the detector.

When comparing LIBS with XRF analysis, there are several other factors to examine. Single LIBS spectrum can be obtained in a fraction of a second, where in an XRF spectrum might take seconds to a few minutes to acquire. As a consequence, LIBS delivers compositional data faster than XRF.

LIBS is a micro-destructive method, since every laser pulse eliminates traces of unsuitable material of the surface from hardwood sample, leading in the formation of a tiny surface crater. [39] As a result, LIBS analysis for a single spot on a wooden sample can indeed be repeated, i.e. a significant disadvantage when analysing objects that are valuable such as cultural heritage artifacts, This is where a micro-destructive method is inappropriate, or when analysing a sample too tiny to yield a significant LIBS spectrum without ruining it completely. [39]

Furthermore, since every laser shot digs a comparable depth into the samples of a dozen of nanometres or less, material removal in a shot after shot method may provide information on the composition of an item at the depth of its function. In XRF case, estimating penetration depth of X-rays is challenging since several variables are involved that are directly linked to the X-ray energy, the greater the energy, the further the penetration into the object. [39]

Depends on the intensity of the sample matrix being examined, the depths toward which X-rays can penetrate a sample matrix is believed to vary from few microns to several millimetres. At most, fluorescent X-rays can be detected from a few centimetres inside the material, although in many instances, this may be lowered to a few micrometres or less. This implies that utilizing XRF to analyse large quantities of earth elements tarnish is a time-consuming and complicated process requiring expertise. [39]

On the whole, LIBS is a useful complement to XRF for material inspection; nevertheless, LIBS seems to be more broadly applicable than XRF for commercial experimental research owing to its capacity to detect light components and complete an analysis more quickly. However, owing to its lower Level of detection of metals, XRF presently has performance benefits in the examination of basic metals and rare earth elements. [39]

4.4 Flow diagram of line construction

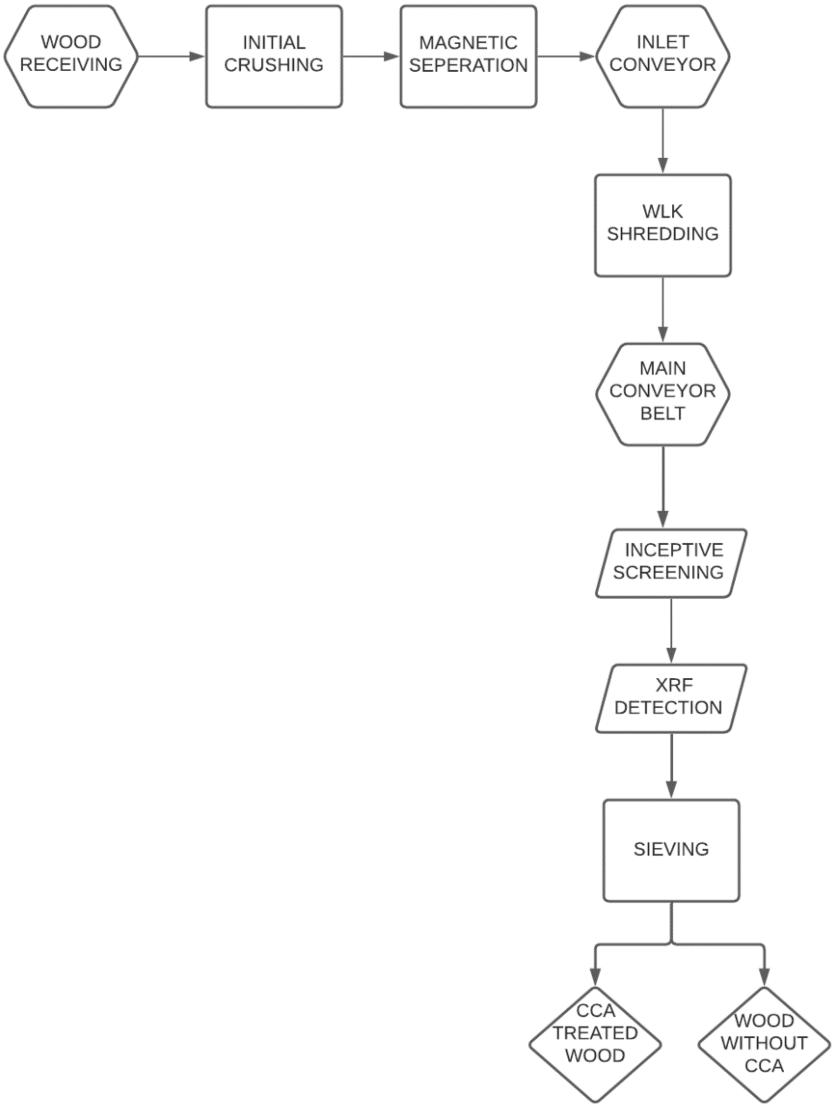

Figure 29. Flow diagram of phases involved in the Line construction for sorting of impregnated wood with the help of an XRF machine.

According to the following resources [51][49][29][50], the following costing of the line construction was compiled from a variety of sources, including the following: Unlike installation costs, which are included in the cost of the bought equipment, yearly cost items are often calculated based on known data about the system size and operating principle, and from the site facilities and control device characteristics, which are not always accurate.

Table 15. In the above table, the total cost estimation of the Line construction is depicted i.e., the impregnated wood processing through stages and undergoes a segregation process with the XRF system.

Line method	Price in Euro (€)
Initial crusher, Magnetic Separation & WLK Shredding	14000
Belt conveyance system	25000
XRF Spectrometer	70000
Sieving	4500
Total	114500

5 CONCLUSION

In this study, there are several fields discussed from pressure treating of wood to sorting efficiencies with advanced measuring technologies and their detailed cost assessments. The focus of this study is to compare a suitable Line construction used in transporting Impregnated wood materials with the high-speed laser detection machines i.e., XRF and LIBS.

According to the data collected, about 6.3 to 6.5 million kilotons of impregnated wood are made in Europe yearly. The European wood industry's production is categorized by product type, with construction timber accounting for 21%, garden timber accounting for 44%, sleepers accounting for 6%, poles accounting for 14%, and tiny roundwood accounting for 15%. Most of the impregnated wood that sustains this present industry (18% is solvent-based, 11% is creosote-based, and 71% is waterborne. In 2012, the Nordic nations produced 2.1 million m^3 of pressure-treated wood for the wood products industry. This facility stocks roughly one-third of the entire European supply of pressure-treated wood.

Sweden is the most prolific producer, followed by Denmark and Norway. Many of Iceland's production facilities do not make use of large-scale injection (a production method that necessitates the use of an impregnation plant).
The overall statistic of wood is collected with regards to Nordics i.e., their annual consumption, production, preservation and supply.

Currently, the use of impregnated wood has seen a 26% rise in Europe, because impregnated wood is stronger than traditional wood that was used in the 20th century. In fact, this method is popular especially in Western countries because it's cheap to impregnate wood and only uses a minimal amount of chemical composition.

A few advantages of impregnated wood used as Light posts, Sauna's, Oceanside sidewalks, Underwater dock pilings, Building construction material, Residential building foundations (Mostly in the Nordics) etc.

The most staggering thing about impregnated wood it is available in many categories i.e., lumber, Plywood, Boards, Posts. Due to its unmatched capacity to resist deterioration, it is excellent for high moisture and/or ground contact applications.

Nonetheless, there is a great deal of misunderstanding, and in some instances, outright misrepresentation, about impregnated wood, its care needs, and its safety in general usage.

According to the previous research, the distance between samples was increased, arsenic counts decreased, but some variations could still be seen at 2.5 cm between the samples. The lower counts observed in untreated wooden samples are most likely due to the lack of chemical impregnation, which was no longer present when the wood was put into service. There were four samples with counts ranging from 100 to 160 that were not treated, and it is very likely that these were left untreated as well. The two samples that vary in recognition by 0.1 cm at 0 and at 1.9 cm distance were two of four that had been presumed of being Un-treated at 0cm.

When measured at a distance of 0cm, the counts per square centimetre (CPS) for these two samples were found to be between 100 and 140, and when measured at a distance of cm, the counts per square centimetre (CPS) were found to be between 50 and 55. This resulted in a two-sample discrepancy in b/w the no.of samples recognized as impregnated at 0cm range when using the recommended threshold settings and the no.of samples are not detected as impregnated when using recommended threshold values.

Using an impregnated and an untreated wood sample, we examined the effect of unique wood characteristics on arsenic count assays. The sapwood (1360) had much higher arsenic than the heartwood (1300). Additionally, the arsenic contents in knots dropped (1240). Without arsenic treatment, the wood was treated with ACQ, CBA, CC, and CDDC.

In the first experiment, the LIBS system accurately identified all but two of the sixty pieces of wood. However, samples 13 and 56 came very near to the instrument's 2.7 limits for this run, suggesting that they were contaminated.

In the second experiment, nine inconsistencies in the XRF datasets were found. This included samples of old, rotting wood, which accounted for the vast majority of wrongly recognized samples.

A previous study shows that 13 out of 100 wood samples are classified erroneously as impregnated or untreated. This is because the baseline for the laser strobes was constantly adjusted manually during the experiment, minimizing inaccuracy. The aim is to study the software used in this study so that it can identify when a baseline has been changed.

Mainly distinguishing between the wet and dry wood was tough for the XRF machine to detect, when it comes to LIBS the accuracy was higher and the results comparing in-between them LIBS has shown remarkable results in detecting wood that contained moisture.

This LIBS equipment, as designed for this investigation, was unable to identify chemicals on coated samples using the ten-shot analysis. However, one noteworthy result of this investigation would be that the system recognized coated surfaces, even transparent coatings that are invisible to the naked eye. Comparing it with XRF, detecting the metal with coated samples was higher and accurate.

Automation techniques have increased the efficacy of sorting systems while also increasing the overall quality, consistency, and safety of the wood sorting process. Sorting methods that are automated may be broadly divided into three types, depending on the degree of automation used.

Overall, when it comes to distinguishing Impregnated wood from other wood types, two sorting methods were investigated: an XRF approach and a LIBS technique. Both technologies were shown to be effective. XRF technology is well suited for sorting tiny amounts of wood and for determining the grade of the wood. Even though LIBS technology has a greater initial investment cost, it has the potential to sort huge amounts of wood logs via the use of an online system.

To summarize, both conveyors offer benefits and drawbacks when it comes to calculating CAPEX AND OPEX for bulk handling. The choice is made here by the particular equipment. Screw conveyors have a greater initial investment and annual operating cost than belt conveyors. Now it completely relies on the material and weight carried from one far location to another in an inexpensive manner, and considering all of the above factors, belt conveyors are the ideal option.

Simultaneously, to handle hazardous substances, choosing screw conveyors is a bright option. However, to maintain the material intact and undamaged with the lesser electricity consumption and low horsepower, A belt conveyor system is much preferred.

REFERENCES

[1] Mathis, D. Blanchet, P. Landry, V and Lagière, P. 2018. Impregnation of Wood with Microencapsulated Bio-Based Phase Change Materials for High Thermal Mass Engineered Wood Flooring. Applied Sciences, vol. 8:12, p. 2696.

[2] Özçifçi, A and Okçu, O. 2007. The influence of the impregnating chemicals on the bonding strength of impregnated wood materials. Journal of Applied Polymer Science, vol 107:5, pp. 2871-2876.

[3] Beckhoff, B. 2006. Handbook of Practical X-Ray Fluorescence Analysis with 385 Figures and 53 Tables, Springer.

[4] Salminen, E. Valo, R. Korhonen, V and Jernlås, R 2014. Wood preservation with chemicals. Copenhagen K: Nordic Council of Ministers, p. 56.

[5] Ministerråd, N. 2014. Wood preservation with chemicals - Best Available Techniques (BAT)Issuu.[Referred:15Mar2021][Online]Availableat:https://issuu.com/nordic_council_of_ministers/docs/tn2014550_web/53.

[6] Baar, J and Gryc, V. 2011. The analysis of tropical wood discoloration caused by simulated sunlight. European Journal of Wood and Wood Products, vol. 70:1-3, pp. 263-269.

[7] Paři, P. 2016. wood impregnation, in impregnation wood methods, czech republic, Mendel University in Brno, p. 152.

[8] Blomberg, J. Persson, B and Blomberg, A. 2005. Effects of semi-isostatic densification of wood on the variation in strength properties with density. Wood Science and Technology, vol. 39:5, pp. 339-350.

[9] Process and composition for impregnating wood and wood products,1972. *Composites*, vol. 3:6, p. 281.

[10] Pressure Treated Lumber Industrial Wood Products, American Pole & Timber, Americanpole&Timber,2021.[Online]Availableat:https://www.americanpoleandtimber.com/wood-timber-products/treatedlumber/

[11] Kokta, B. Maldas, D. Daneault, C and Béland, P. 1990. Composites of poly(vinyl chloride) and wood fibers. Part II: Effect of chemical treatment, Polymer Composites, vol. 11:2, pp. 84-89.

[12] Wood peelers | Bezner-Oswald. 2021. [Referred: 03- Apr- 2021]. [Online] Available at: https://www.bezner-oswald.com/products/wood-peelers/

[13] Incised timber ECC.ie. 2021. [Referred: 03Apr2021]. [Online] Available at http://www.ecc.ie/incised-timber.

[14] Vacuum Pressure Impregnation Systems IMP-VP: introduction - ISVE Wood - Lumber treatment, ISVE Wood - Lumber treatment. 2021. [Referred: 05- Apr- 2021].[Online] Available at: https://www.isvewood.com/en/imp-vp-wood-impregnator-introduction/

[15] Civardi, C. Schwarze, F and Wick, P, 2015. Micronized copper wood preservatives: An efficiency and potential health risk assessment for copper-based nanoparticles, Environmental Pollution, vol. 200: 126-132.

[16] Hou, X. and Jones, B. 2000. Field instrumentation in atomic spectroscopy. Microchemical Journal, vol 66 : 3, pp.115-145.

[17] H Pinto, A. 2018. Portable X-Ray Fluorescence Spectrometry: Principles and Applications for Analysis of Mineralogical and Environmental Materials. Aspects in Mining & Mineral Science,1(2).

[18] Yu, K. Ren, J. and Zhao, Y. 2020. Principles, developments and applications of laser-induced breakdown spectroscopy in agriculture: A review. Artificial Intelligence in Agriculture, vol 4 , pp.127-139.

[19] Freeman, M & Mcintyre, C. 2008. Copper-Based Wood Preservatives A Comprehensive Review of Copper-Based Wood Preservatives. For Prod J. 58.

[20] Akhtar, M. Jabbar, A. Mehmood, S. Ahmed, N. Ahmed, R. and Baig, M. 2018. Magnetic field enhanced detection of heavy metals in soil using laser induced breakdown spectroscopy. Spectrochimica Acta Part B: Atomic Spectroscopy, pp.143-151.

[21] Rapid Elemental Analysis and Provenance Study of Blumea balsamifera DC Using Laser-Induced Breakdown Spectroscopy., 2015. [Referred: 15 May, 2021]. Scientific Figure on ResearchGate. [online] Available at: https://www.researchgate.net/figure/Schematic-diagram-of-LIBS system_fig1_270652824.

[22] Hasan, 2009. Studies on weathered waterborne treated wood: Leaching of metals during service and metals based sorting upon recycle. PH.D university of Miami.

[23] Blassino, M & Solo-Gabriele, H & Townsend, T. 2002 . Pilot-scale evaluation of sorting technologies for CCA treated wood waste. Waste management & research: the journal of the International Solid Wastes and Public Cleansing Association, ISWA. 20. 290-301. 10.1177/0734242X0202000310.

[24]Malvernpanalytical.com.2021. [Referred:19May2021].EnergyDispersiveSpectroscopy EDXRFSpectrometers|EDXAnalysis.[online]Availableat:https://www.malvernpanalytical.com/en/products/technology/xray-analysis/x-ray-fluorescence/energy-dispersive-x-ray-fluorescence

[25] Xos.com. 2021. [Referred: 19 May 2021]. Wavelength Dispersive X-ray Fluorescence (WDXRF) - XOS. [online] Available at: https://www.xos.com/WDXRF

[26] Malvernpanalytical.com. 2021. [Referred: 19 May 2021]. *WDXRF* | Wavelength DispersiveXRayFluorescenceSpectroscopy.[online]Availableat:<https://www.malvernpanalytical.com/en/products/technology/xrayfluorescence/wavelengthdispersivexrayflourescence/>

[27] Easternapplied.com. 2021. [Referred: 19 May 2021]. X-ray Fluorescence Technology (EDXRFversusWDXRF)|EasternAppliedResearch,Inc.[online]Availableat:<http://www.easternapplied.com/blog/laboratory-equipment/types-xrf-spectrometers/>

[28] Bruker.com. 2021. [Referred: 1 June 2021].S6 JAGUAR. [online] Available at: https://www.bruker.com/en/productsandsolutions/elementalanalyzers/xrfspectrometers/s6-jaguar.html

[29] Hasan, A. Solo-Gabriele, H. and Townsend, T. 2011. Online sorting of recovered wood waste by automated XRF-technology: Part II. Sorting efficiencies. Waste Management, vol 31:4, pp.695-704.

[30] Solo-Gabriele, H. Townsend, T. Hahn, D. Moskal, T. Hosein, N. Jambeck, J. and Jacobi, G. 2004. Evaluation of XRF and LIBS technologies for on-line sorting of CCA-treated wood waste. Waste Management, vol 24:4, pp. 413-424.

[31] Dubey, B. Townsend, T. and Solo-Gabriele, H. 2007. Impact of Surface Water Conditions on Preservative Leaching and Aquatic Toxicity from Treated Wood Products. Environmental Science & Technology, vol 41:10, pp. 3781-3786.

[32] Noll, R. Begemann, F. Connemann, C. Meinhardt, Sturm, V. 2018. LIBS analyses for industrial applications – an overview of developments from 2014 to 2018. Journal of Analytical Atomic Spectrometry, vol 33:6, pp.945-956.

[33] Ltb-berlin.de. 2021. [Referred: 4 June 2021]. LTB Lasertechnik Berlin. [online] Available at: http://www.ltb-berlin.de/en/products/spectrometers/aryelle-400/

[34] Moskal, T. and Hahn, D. 2002. On-Line Sorting of Wood Treated with Chromated Copper Arsenate Using Laser-Induced Breakdown Spectroscopy. Applied Spectroscopy, vol 56:10, pp.1337-1344.

[35] Ukushima, Y. Furuya, Y. Maenami, K. and Ajioka, Y . (2001) : Study on Recycling Scraped wood with which medicine processing of antiseptics, antifungal agents and insecticides were performed. Bullein of Shizouka institute of environ. pp.67-74.

[36] Composites, 1988. Preservative treated composite wood product, vol 19:1, p.83.

[37] Jacobi, G. Solo-Gabriele, H. Townsend, T. and Dubey, B. 2007. Evaluation of methods for sorting CCA-treated wood. Waste Management, vol 27:11, pp.1617-1625.

[38] Senesi, G. Harmon, R. and Hark, R., 2021. Field-portable and handheld laser-induced breakdown spectroscopy: Historical review, current status and future prospects. Spectrochimica Acta Part B: Atomic Spectroscopy, vol 175, pp.106-130.

[39] Rakovský, J. Čermák, P. Musset, O and Veis. P, 2014. A review of the development of portable laser induced breakdown spectroscopy and its applications. Spectrochimica Acta Part B: Atomic Spectroscopy, vol 101, pp.269-287.

[40] CDM Systems, Inc. 2021. The most efficient conveying technologies for bulk material handling. [online] Available at: <https://www.cdmsys.com/conveying-comparison-what-are-the-most-efficient-conveying-technologies-for-bulk-material-handling/>

[41] Tecnitude.com. 2021. Wood belt conveyor: sawmill, sawdust, wood chips transport. [online] Available at: <https://www.tecnitude.com/en/wood-product-transportation>

[42] Wood Business. 2021. Tech update: Infeed systems - Wood Business. [online] Available at: <https://www.woodbusiness.ca/tech-update-infeed-systems/#>

[43] FEECO International Inc. 2021. When to Choose a Belt Conveyor Over a Screw Conveyor. [online] Available at: <https://feeco.com/bulk-material-handling-when-to-choose-a-belt-conveyor-over-a-screw-conveyor/>

[44] Dynamics, C. 2021. [Referred: 28 September 2021]. Feasibility studies. [online] Conveyor Dynamics, Inc. Available at: <https://cvdyn.com/>

[45] Weima.com. 2021. [Referred: 28 September 2021]. *Weima shredding + briquetting*. [online] Available at: https://weima.com/wp-content/uploads/2017/11/woodwolf.pdf

[46] Boslovyak, P. and Lagerev, A. 2019. Optimization of the conveyor transport cost. IFAC-Papers Online, vol 52:25, pp.397-402.

[47] Pieber, M. 1977. [Referred: 29 September 2021]. Comparative coal transportation costs: An economic and engineering analysis of truck, belt, rail, barge and coal slurry and pneumatic pipelines. [online] Available at: <https://www.osti.gov/servlets/purl/6073477>

[48] Niaounakis, M. 2020. Recycling of flexible plastic packaging. Cambridge, MA 02139, United states: Matthew deans.

[49] Reddy, n. 2021. Regarding capital and operational cost assessment of belt and screw conveyor system. [email].

[50] Foeth.com. 2021. [Referred: 4 October 2021]. Disintegrator Powder sieving machine - Vibrio sieve. [online] Available at: <https://www.foeth.com/en/sieves/vibro-sieves/dezintegrator-powder-sieving-machine-330s603>

[51] Alibaba.com. 2021. [Referred: 4 October 2021]. Hot Selling Log Splitter Tree Cutting Waste Wood Pellet Making Machines Forestry Mulcher Machinery Wood Shredder Chipper - Buy Forestry Machinery Wood Chipper, Forestry Waste Wood Pellet Making Machines, Hot Selling Wood Chipper Product on Alibaba.com. [online] Available at: <https://www.alibaba.com/productdetail/WoodMachinesMachineryChipperHotSelling_1600330088882.html?spm=a2700.7724857.normal_offer.d_image.30c3592fEyAolF&s=p>