ELECTRON BEAM BASED LEATHER TANNING

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Abstract

Tanning of leather for clothing, shoes, and handbags uses potentially harmful chemicals that often run off into local water supplies or require a large carbon footprint to safely recover these pollutants. In regions of the world with significant leather production, this can lead to a significant environmental impact. However recent studies have suggested that leather can instead be tanned using a combination of electron beams in a process inspired by the industrial crosslinking of polymers, to drastically reduce the quantity of wastewater produced in the process; thereby resulting in a reduced environmental impact as well as potential cost savings on wastewater treatment. In this talk, initial studies of leather tanning will be presented as well as accelerator designs for use in leather irradiation.

INTRODUCTION

Particle accelerators have been used for many industrial applications like radiotherapy treatment, cargo scanning, material modification, medical sterilization, food processing, and polymer crosslinking [1,2]. Particle accelerators have great potential for developing disruptive technologies in a world with an increasing demand for green technology and sustainability. One of those potential applications is using an electron beam from accelerators for leather manufacturing, which we call e-beam tanning for brevity. The e-beam tanning process is similar to the crosslinking of polymers. The collagen in the animal hide is equivalent to polymers; similarly, tannin is the cross-linking agent. The whole e-beam tanning process is shown in the diagram in Fig. 1. The hide is soaked in the tanning agent bath before the treatment so the tannin is permeated throughout the hide. The mixture of tannin and hide is then irradiated by the electron beam, which will initiate the cross-linking process. The leftover bath is replenished and reused. The hides are placed on a conveyor belt and irradiated by the electron from the top. The electron beam is scanned in the perpendicular direction to the hide movement.

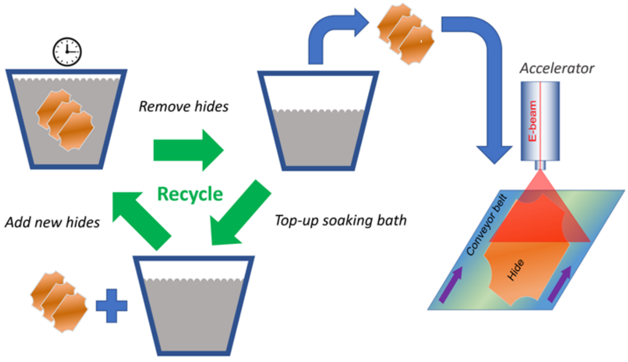

Figure 1: E-beam tanning process diagram.

In the conventional tanning process, the hides are tanned inside a tanning drum with a tanning bath. When tanning is finished, the leftover tanning bath is discharged as wastewater, which will require treatment as it contains tannins and other chemicals. The wastewater treatment process is an energy-intensive and costly process. In the e-beam tanning process, however, the hide is only soaked inside the bath, hence it can be replenished and reused and no substantial amount of wastewater is generated. The tannin uptake efficiency can be close to 100%. Another advantage of e-beam tanning is it is able to occur over a wider range of temperatures and pH, while also allowing for the use of novel tanning agents that would typically be too unstable in water or air to bind to the collagen.

One of the key challenges of e-beam tanning is the uniformity of the tanning reaction throughout the cross-section of a hide, which is crucial for the end product to achieve tight specification parameters set by the original equipment manufacturers (OEMs) as well as meeting legislative restrictions. Uniform tanning would require uniform energy deposition by the electron beam. In this study, we use Monte Carlo simulations to design and optimize the electron beam-based leather treatment system to achieve uniform dose deposition, while keeping the system design simple, scalable for industrial production, and energy efficient.

ELECTRON BEAM TREATMENT SYSTEM DESIGN

Electron Beam Energy

The first key parameter we need to find out for the irradiation system is the beam energy, as it will dictate the accelerator size, operating power, and related costs. The beam energy determines the penetration depths in the hide. When it is too low, the energy is only deposited on the surface, which will result in poor uniformity. On the other hand, when it is too high, most electrons will penetrate through without depositing enough energy, which results in low effi-

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ciency. So we need to find appropriate energy for a given hide thickness first. We used G4beamline [3], which is a particle tracing simulation program based on Geant4 [4], to simulate dose deposition. It can simulate the interaction of the high electron beam with matters and estimate dose distribution.

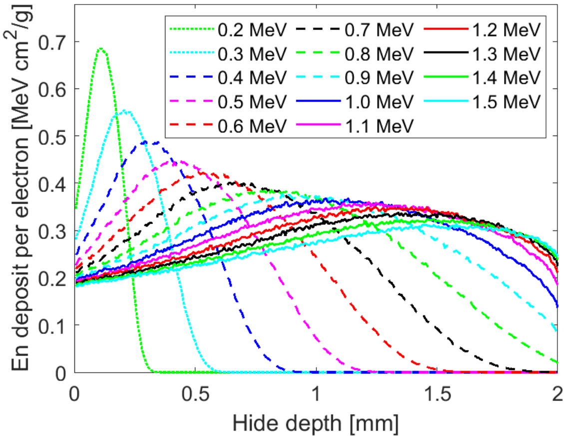
During the optimization process, we need to keep in mind that we want to achieve 2 goals: dose uniformity and energy efficiency. The energy efficiency is measured as the percentage of the electron beam energy deposited into the hide. High efficiency is important as it will lower power consumption and save costs.

The dose uniformity can be separated into two transverse and longitudinal uniformity. The transverse dose uniformity can be achieved by using a raster magnet to steer the beam across the hide [5]. The longitudinal dose uniformity, which is the uniformity along the hide depth, can be achieved by optimizing the beam energy, placing a metal plate on the back of the hide, and treating the hide twice from both sides.

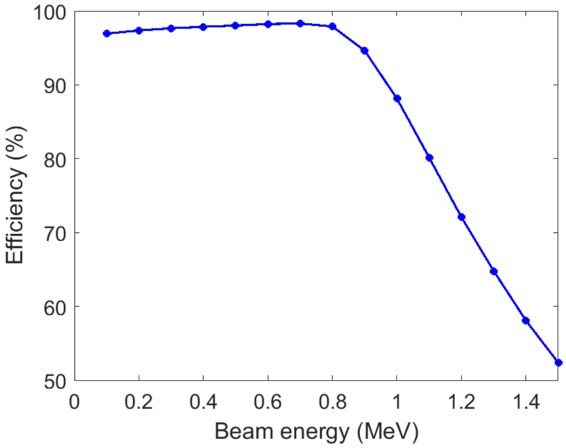
In this work, we will optimize the irradiation system for bovine car leather, which has a typical thickness of less than or equal to 2 mm. The density of the soaked bovine hide before the treatment is measured to be around 1.5 g/cm^3, which is 1.5 times the water density. The soaked hide is a mixture of collagen, tannin, and other chemicals, hence it is not a readily available material in the simulation program. Hence, we used 3 mm of water in our simulations instead of 2 mm hides, as they are equivalent (with good approximation) from the irradiation/energy deposition perspective.

In our simulations, we fired electrons on the 2 mm hide, and beam energy increased in 0.1 MeV intervals. The hide is divided into many layers and the energy deposited per electron in each layer is calculated and given in Fig. 2. When the energy is lower than 0.5 MeV, no energy is deposited to the back half as can be seen in sub-figure (a). So, the beam energy can not be lower than 0.5 MeV, as we will not be able to deposit energy to the center of the hide even if we treat the hide from 2 sides. This is our lower bound of the beam energy.

The dose distribution tends to get flattered as the energy increase, but efficiency drops as well, as can be seen in sub-figure (b). We see when the beam energy is ≥0.8 MeV, the energy deposition at the end of the hide is not zero, which means some electrons penetrated through the hide at this energy. This is also the reason the energy efficiency starts to drop when beam energy is ≥0.8 MeV. We want to achieve 50% or higher efficiency, which gives us the upper limit for the beam energy of 1.5 MeV. So, we preliminarily conclude the beam energy should range from 0.5 to 1.5 MeV to achieve reasonable and balanced dose uniformity and energy efficiency.



(a)



(b)

Figure 2: Electron beam dose deposition simulation results: (a) longitudinal dose distribution with different beam energy and (b) energy efficiency.

Two-sided Treatment

One of the simple and easy-to-implement techniques is to use the two-side treatment. In this process, the hide will be treated first from one side, then filliped and treated for the second time. As the hide is treated from both sides, the electron beam energy can be lower as it only needs to penetrate half of the thickness. This allows us to use lower beam energy while increasing efficiency and dose flatness, as can be seen from Fig.3. The red and green curves are dose distribution when treated from the front and back sides of the hide, respectively. Combining these two curves gives us the dose distribution of the two-side treatment, which is indicated by the blue curve. We can see the 2-side treatment has better flatness compared to the single treatment while the efficiency is as the single treatment.

Metal Back Plate

In earlier simulations, the hide is placed in the air. So, the electrons penetrated through the hide are lost. If we place a metal plate as shown in the diagram in Fig. 4, we can reflect some energy back into the hide otherwise would be lost. This can further increase efficiency and, more importantly, increase flatness.

Our simulation studies showed that 2 mm Cu is thick enough for a 2 mm hide. The dose distribution with and

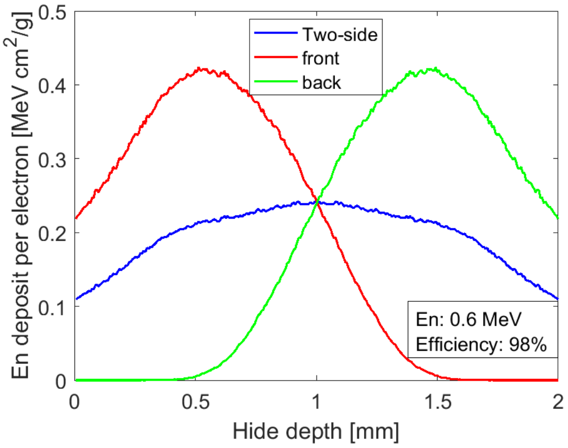


Figure 3: Electron beam energy deposition of two-side treatment.

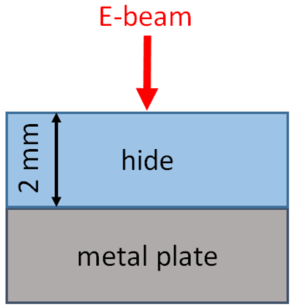
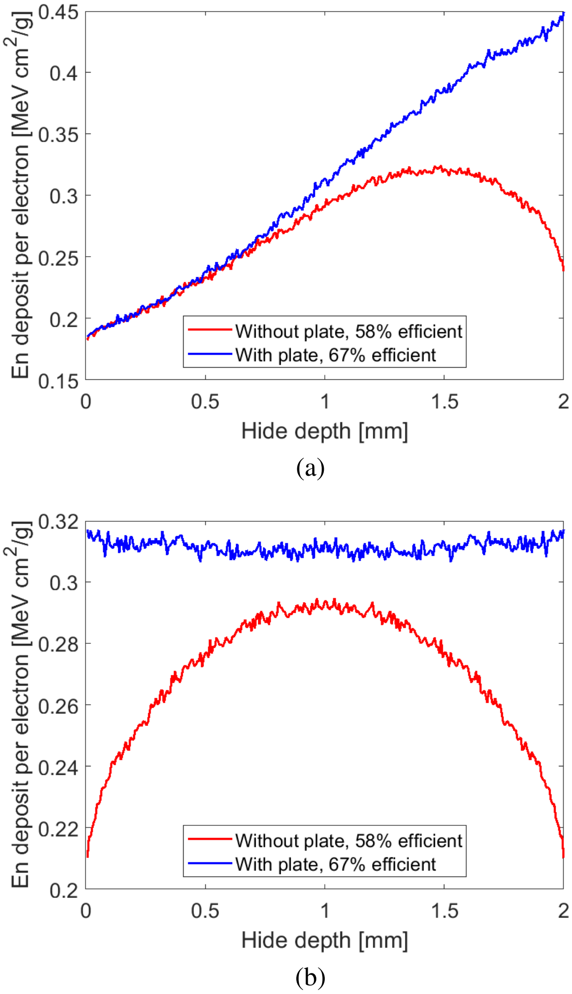


Figure 4: Diagram for treatment with metal back plate.

without a 2 mm copper plate is shown in Fig. 5 for comparison. Sub-figure (a) shows the single side treatment with the plate. We can see the blue curve is much higher at the back side of the hide, which indicates some particles are reflected back to the plate. As a result, the efficiency is increased from 58% to 67%. Also, with the plate, the dose curve is close to a straight line, which is a useful feature we can exploit to generate a uniform dose curve by combining it with the 2-side treatment, as shown in sub-figure (b). The average of two straight lines with opposite slopes is a flat line with a y-offset but no slope. Therefore, we can see the combined effect of the back plate and 2-side treatment is a near flat dose curve in sub-figure (b). We performed a beam energy scan and the results are given in Fig. 6. We can see the dose distribution of the 1.4 MeV is the flattest one with an efficiency of 67%, which is reasonable.

Plate Material and Thickness Considerations

We simulated 3 types of metal materials for the back plate, copper, lead, and iron, to check the impact of the different materials on the energy deposition. The results are given in Fig. 7. We used 5 mm thick plates so the plate is thick enough for all 3 materials. We can see the copper and iron plate have similar dose flatness, while the lead plate has the worst



(a)

(b)

Figure 5: Longitudinal energy deposition with (blue) and without (red) 2 mm Cu back plate of the 1.4 MeV beam: (a) single side treatment (b) 2-side treatment.

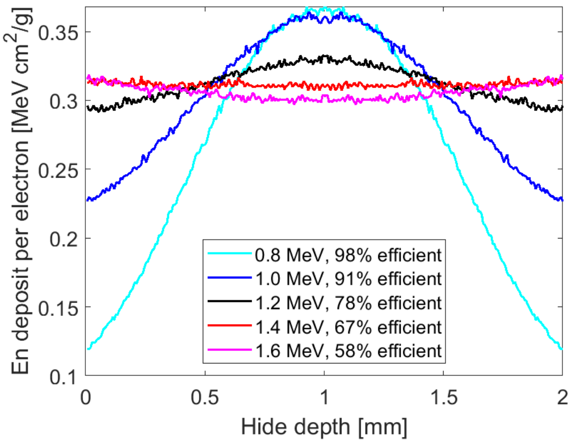


Figure 6: Longitudinal energy deposition with 2-side treatment and 2 mm Cu back plate at different energies.

flatness. Hence, we conclude both iron and copper are good options. We also observed there is no difference in energy distribution between the 5 and 2-mm thick copper plates, hence we conclude 2 mm copper plate is thick enough.

Quantifying Dose Flatness

We can quantify the dose uniformity by using σ_D/D_{ave} (the relative standard deviation of dose), which is the ratio of the standard deviation of dose σ_D to the average dose D_{ave}. Both σ_D/D_{ave} and energy efficiency are functions of beam energy and the relation can be seen in Fig. 8. Now, we can quantitatively confirm that 1.4 MeV is the best energy for dose uniformity.

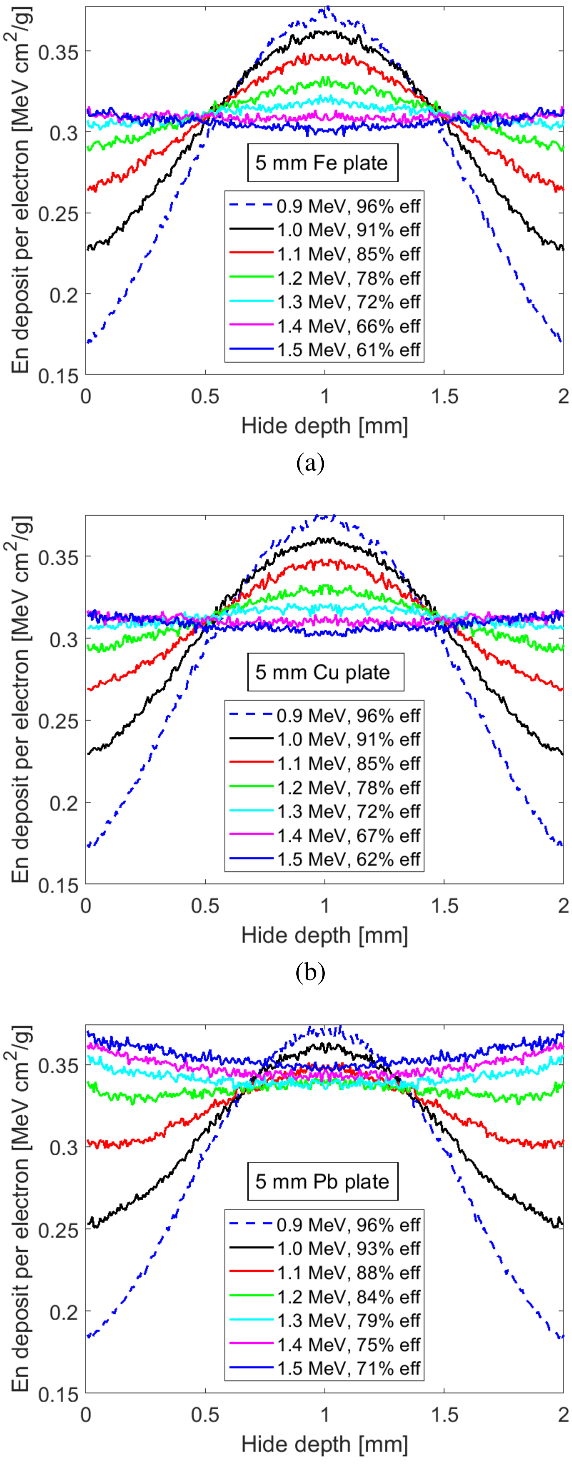
OPTIMAL ENERGY FOR DIFFERENT THICKNESS OF HIDES

So far we have only found the optimal treatment energy for the 2 mm hides. We performed similar studies for other thicknesses to find optimal beam energy. The energy scan results for other thicknesses are given in Fig. 9. The sub-figure (a) shows the σ_D/D_{ave} and (b) shows efficiency as a function of beam energy. The dots are the minimum σ_D/D_{ave} points and they range from 0.006-0.008. We can see these optimal energies can achieve energy efficiency of around 70-80%.

We used the minimum σ_D/D_{ave} points in Fig. 9 and plotted their beam energy *vs* hide thickness, as shown in Fig.10. We can see the relations are linear and the fit results are given in the figure. By using this linear fit, we can establish a rule of thumb for quickly determining the optimal beam energy with the best dose uniformity for an arbitrary thickness. We can roughly estimate the σ_D/D_{ave} to be around 0.006-0.008 and the efficiency to be around 70-80%, based on our simulation results. We can see for a 2 mm hide, the 1.4 MeV beam energy is sufficient, while a 20 mm hide would require 8.8 MeV beam energy.

CONCLUSION

Electron beam leather tanning is a promising technology that can reduce the cost and save chemicals and water. As the technology is still at its early stage, the irradiation system is yet to be designed and optimized. In this work, we have presented our design study and we addressed key challenges. Firstly, we have estimated proper beam energy for 2 mm thick bovine hide. Based on that, we proposed a design that can generated uniform dose distribution and hence uniform tanning, while maintaining high efficiency, which uses a back metal plate and two-side treatment. We used σ_D/D_{ave} to quantitatively evaluate the dose uniformity. We found that 1.4 MeV is the best energy range to achieve high uniformity and efficiency for treating a 2 mm thick hide. We further extended our studies to other hide thicknesses by performing an energy scan and estimating their uniformity and efficiency. These results can be used as a lookup table to quickly determine the best electron beam energy for a given hide thickness. With our design we can achieve σ_D/D_{ave} of around 0.006-0.008 and the efficiency of around 70-80%. Our treatment method is simple and scalable, which can be easily implemented for industrial treatment.



(a)

(b)

(c)

Figure 7: Longitudinal energy deposition of the 5-mm thick (a) iron, (b) copper, and (c) lead plates.

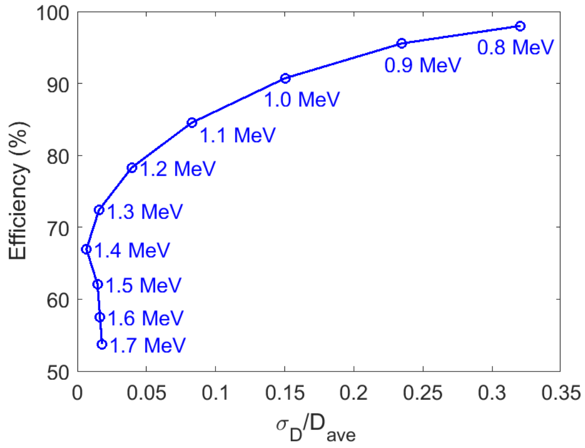
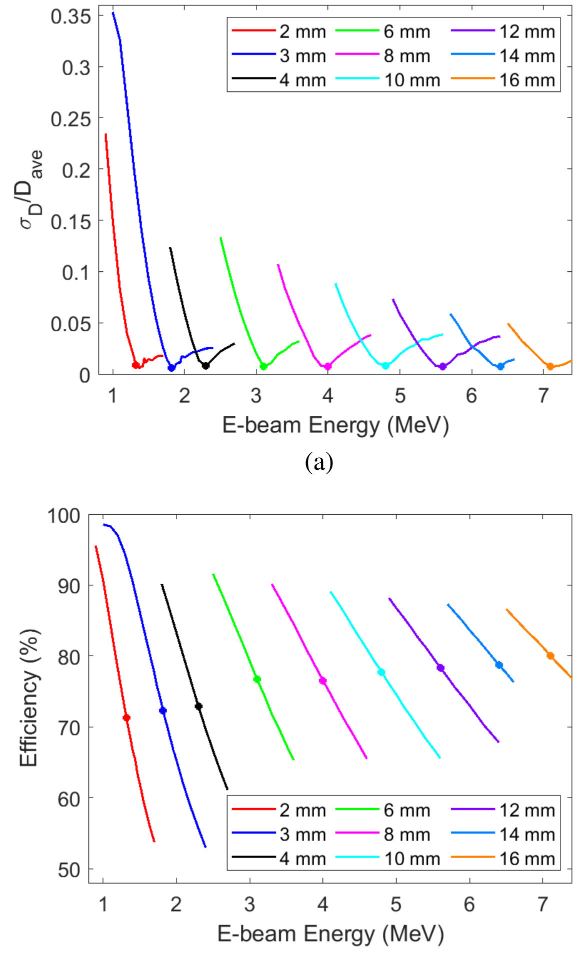


Figure 8: Efficiency and relative standard deviation of dose as function beam energy. The blue text in the figure indicates beam energy.



(a)

(b)

Figure 9: Electron beam energy scan results: (a) σ_D/D_{ave} and (b) energy efficiency as a function of beam energy. The dots correspond to minimum σ_D/D_{ave} points.

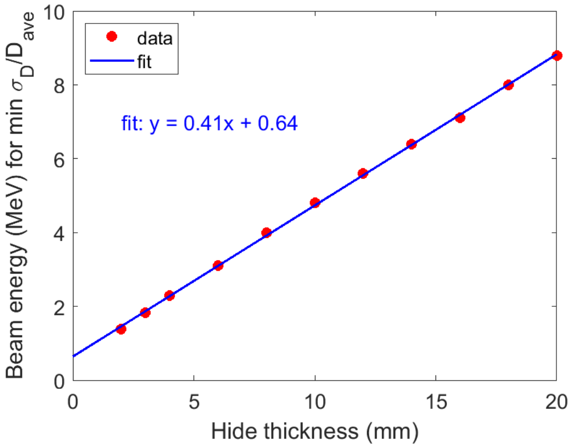


Figure 10: Beam energies to generate best dose uniformity for different thicknesses of hides.

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REFERENCES

[1] W. Scharf and W. Wieszczycka, `https://doi.org/10.1063/1.59300`, AIP Conference Proceedings 475, 949-952, 1999.

[2] I. Klier and A. Vokál, `https://doi.org/10.1016/1359-0197(91)90061-6`, Radiat. Phys. Chem. Vol. 38, No. 5, pp. 457 160, 1991.

[3] G4beamline Release 3.06 (January 2019). `http://www.muonsinternal.com/muons3/G4beamline`, (accessed on 16 June 2022).

[4] S. Agostinelli, Geant4—A Simulation Toolkit. *Nucl. Instruments Methods Phys. Res.* , **2003**, *506*, 250–303, doi:10.1016/S0168-9002(03)01368-8.

[5] R. Apsimon, S. Setiniyaz, R. Seviour, W. Wise, T. Junginger, M. J. Hernandez, and E. Ortiz, `https://doi.org/10.3390/physics3020017`, Physics, 3, 220-239, 2021.