RELIEF: Tanning of Leather with e-beam

WE2AA02

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Overview

- What is tanning?
- Environmental impact
  - *Chromium*
  - *Wastewater/effluent*
- E-beam tanning
  - *Concept*
  - *Benefits*
- Simulation results
- Summary and conclusions

What is tanning?

- Tanning is a chemical process to modify the physical and chemical properties of hides
  - Prevent biological degradation (putrefaction)
  - Improve durability, tensile strength etc (depends on end user requirements)
- This involves creating branching and/or crosslinking between protein chains
  - This depends on which tanning agents are used.
    - Branching: results in more flexible leather for handbags, jackets etc
    - Crosslinking: stiffer, more durable leather, used for boots and furniture

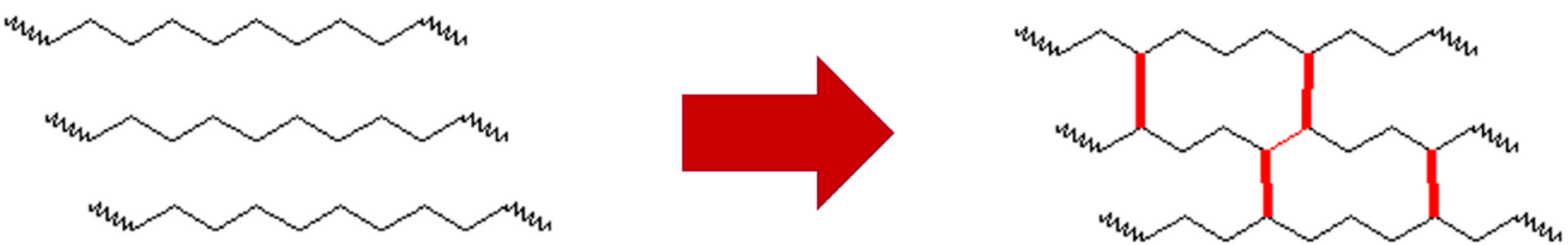


Image source: http://chemistry2.csudh.edu/rpendarvis/Polymer.html

What is tanning?

- Tanning is achieved by adding chemicals to the hides, which bind to the proteins.
  - The chemicals are called tanning agents, tannins or tannages.
- There are three main classes of tanning agents:
  - 80% of the world's leather is produced with chrome (III) sulphate due to the high quality end product.
  - These chemicals can have an acute impact to the local environment if not properly treated and disposed of.

Synthetic tannins | Metal tannins | Vegetable tannins

Image source: https://www.leather-dictionary.com/index.php/Tannins

Conventional tanning

- Hides are conventionally tanned in large drums, which can hold up to 500 – 600 hides and 20 – 40 tons of water and chemicals.
- The process takes 12 – 36 hours for metal and synthetic tannins
  - Veg tanning can take up to 1 year
- Tanning drums use 150 – 250 kW of power to mix hides and tanning solution

The mechanical action of turning the drums produces heat, to keep the mixture at ~30^{o}C.

Most large tanneries use conveyor systems to transport hides from one area to the next.

This is a picture of a tannery we visited in Mexico.

Environmental impact: chromium

- Most common oxidisation states are Cr(III) and Cr(VI)
  - Cr(III) is stable, **green** in colour and benign as it can't pass through cell membrane.
  - Cr(VI) is less stable, **red or orangey-yellow** in colour and is **hemotoxic, genotoxic and carcinogenic**.
    - Small enough to pass through cell membrane, reduces to Cr(III) and tans DNA!
  - Cr(III) can be oxidised to Cr(VI) by sunlight or acidic conditions

- What if chromium wastewater is improperly disposed of in the local environment?
  - Chromium contaminates water supplies
  - Ingested by animals and absorbed by plants within the watershed
  - By contaminating food and water supplies, chromium persists within the local environment.

Environmental impact: wastewater/effluent

- How wastewater and effluent is dealt with can vary significantly around the world, depending on factors such as environmental policies, regulation and enforcement.
  - However, regardless of whether wastewater is disposed of in a lake/river, or treated in a specialist effluent treatment plant, there is still an environmental impact to consider.

Guanajuato, Mexico

Water treatment plant

Image source (right image): https://envirotech.com/wastewater/

Environmental impact: wastewater/effluent

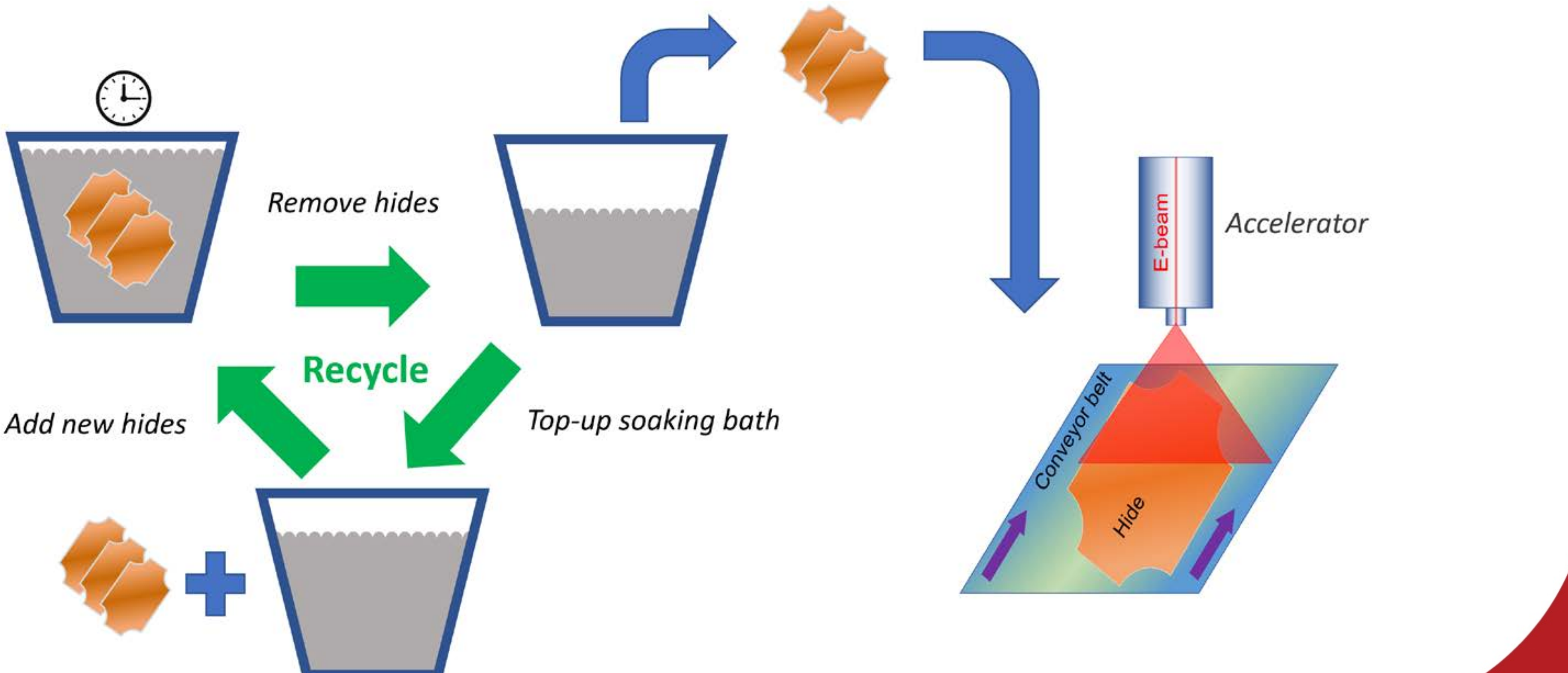
- **Improper disposal/discharge of effluent**
  - This may be discharged into lakes/rivers or a domestic sewage treatment plant
  - Long-term contamination of local food and water supplies
  - Increasing focus on green credentials
  - Enforcement of policies requires resources and will impact leather industry
    - This may have major consequences on economy in lower-income countries.

- **Wastewater treatment**
  - Removes hazardous chemicals from wastewater that domestic sewage treatment plants can't
  - Energy intensive process with large carbon footprint
  - Significant cost to tanneries (30 – 50% of total production cost of leather)

- **Solution to both problems is to eliminate wastewater production**

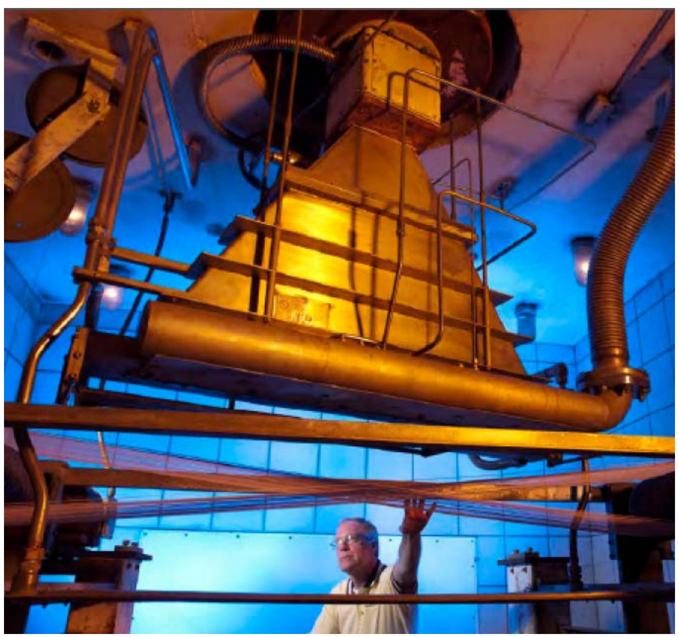
E-beam tanning: concept

- Our solution: soak the hides in the required tanning agents, then irradiate with an electron beam to tan the hides



E-beam tanning: concept

- Our process is inspired by the industrial crosslinking of polymers to modify its material properties
  - This is very often achieved with electron beams
  - Instead of polymers, we are modifying proteins



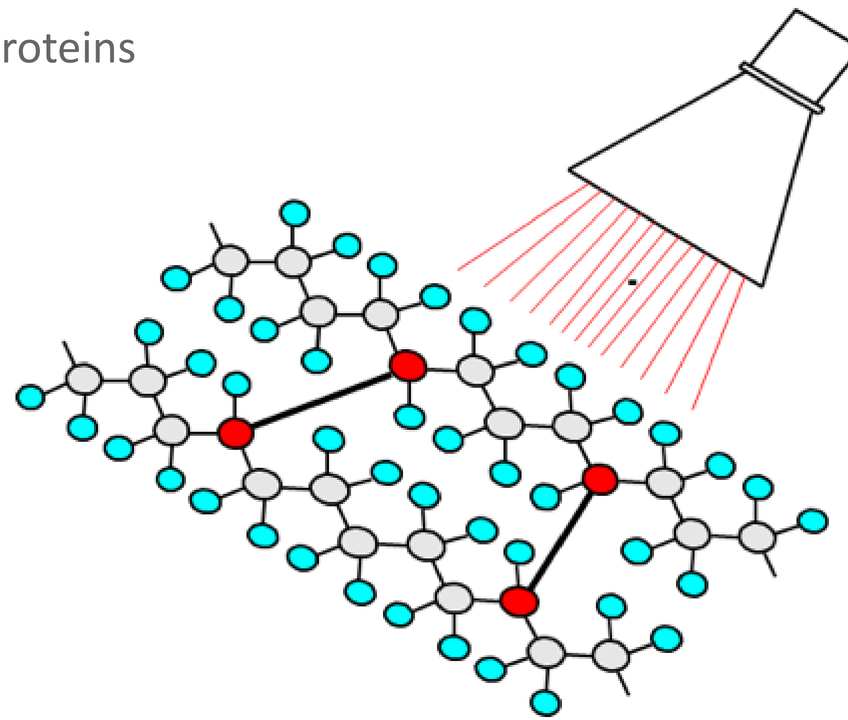


Image source (right image): https://www.miottisrl.com/en/does-the-radox-cable-radiation-cross-linking-process-occur/

E-beam tanning: benefits

- Compared to conventional drum tanning, e-beam tanning has the following benefits:
  - ~90% reduction in wastewater production
    - Any drippage pre-irradiation can be recycled
  - Reduction in water (~50%) and energy (~10%) consumption during tanning stages
    - This excludes indirects such as wastewater treatment
  - Turns tanning from a batch process to a continuous process
  - By instantaneously tanning (rather than taking 12 – 36 hours), novel tanning agents could be used which are too unstable for conventional tanning

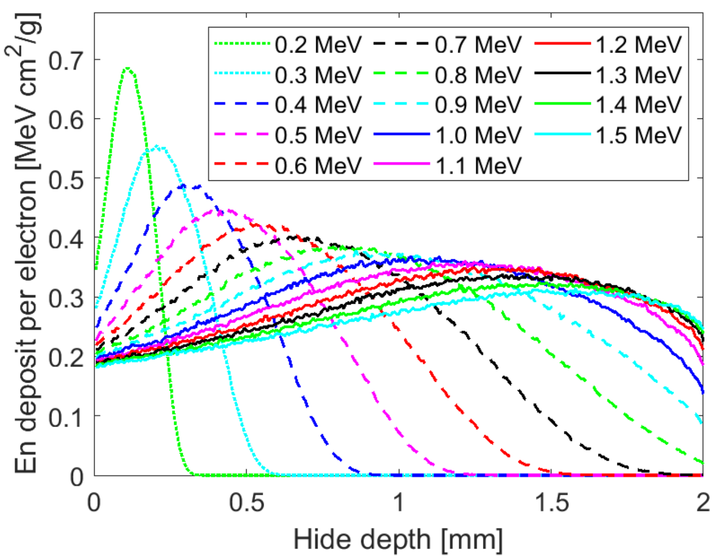
Accelerator requirements

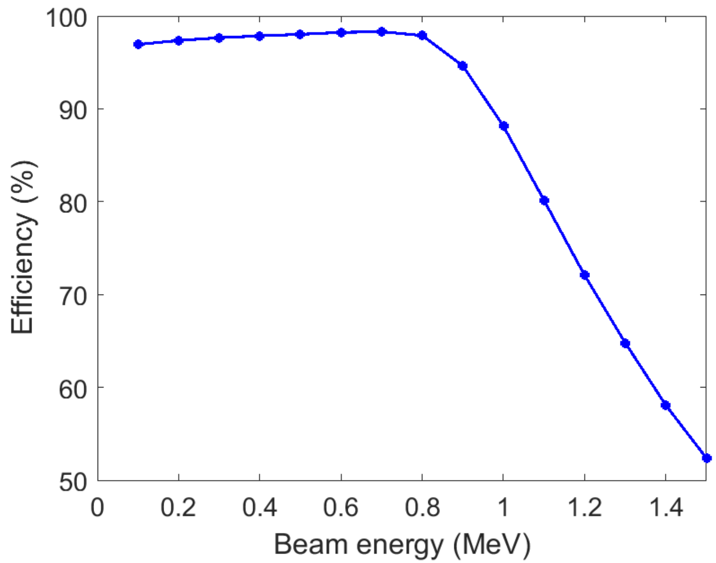
- Conventional tanning:
  - 1 tanning drum tans 500 – 600 hides in 12 – 36 hours (~1 – 3 minutes per hide)
  - Requires 20 – 40 tons of water
  - 150 – 250 kW of power to run the tanning drums
  - A tanning drum costs ~£100k – 250k and will last ~10 years

- E-beam tanning:
  - ~ 0.4 MeV/mm of hide thickness (2 – 10 mm depending on requirements)
  - Assume 200 kGy required dose, need ~45 kW beam power to tan 1 hide in 90 s
    - For a 2 mm thick hide
  - Accelerator costs >£1M depending on specific requirements
    - E-beam tanning cost effective for medium/large tanneries (>200k hides/year)
  - Need to optimise dose distribution and energy efficiency

Single-sided irradiation

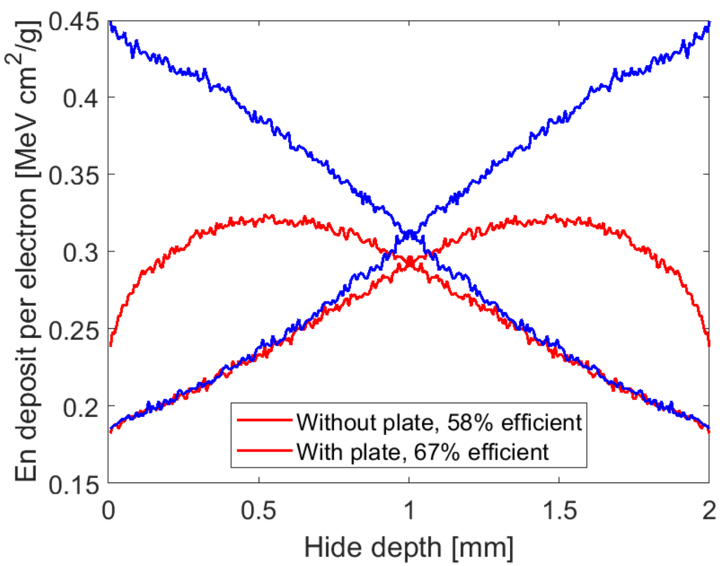
- Soaked bovine hide has a density of ~ 1.5 g/cm^3
- Figures of merit:
  - Energy deposition efficiency: $\eta_E = \frac{E_{deposited}}{E_{beam}}$
  - Dose uniformity: $\frac{\sigma_D}{D_{ave}}$

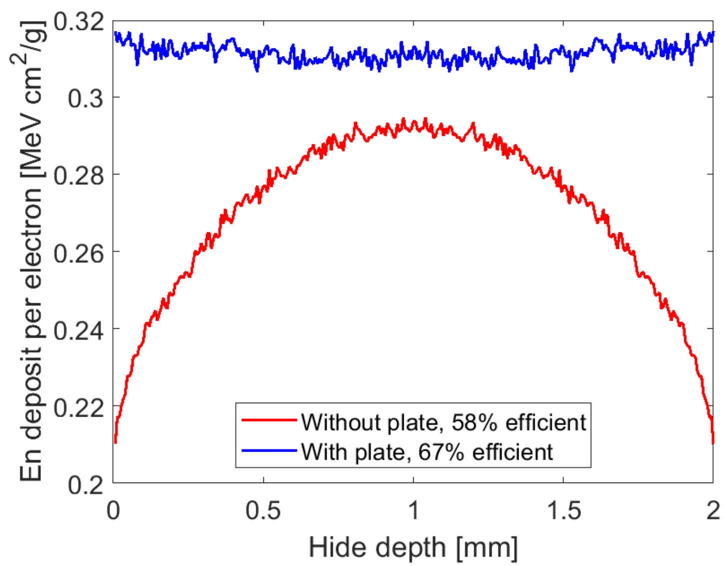




Double-sided irradiation

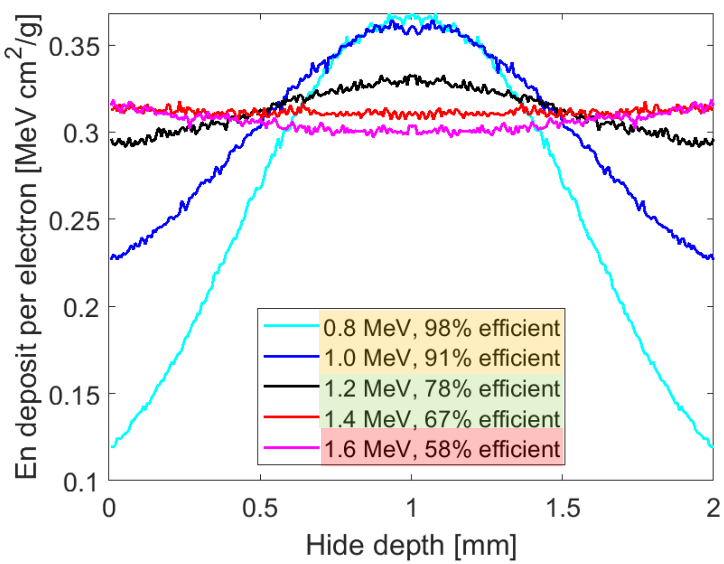
- Irradiate hide, flip it over an irradiate the other side
- Metal back plate to backscatter electrons that pass through the hide
  - Allows a "second bite of the cherry" increasing both η_E and σ_D/D_{ave}
  - The beam energy needs to be tuned to the required hide thickness

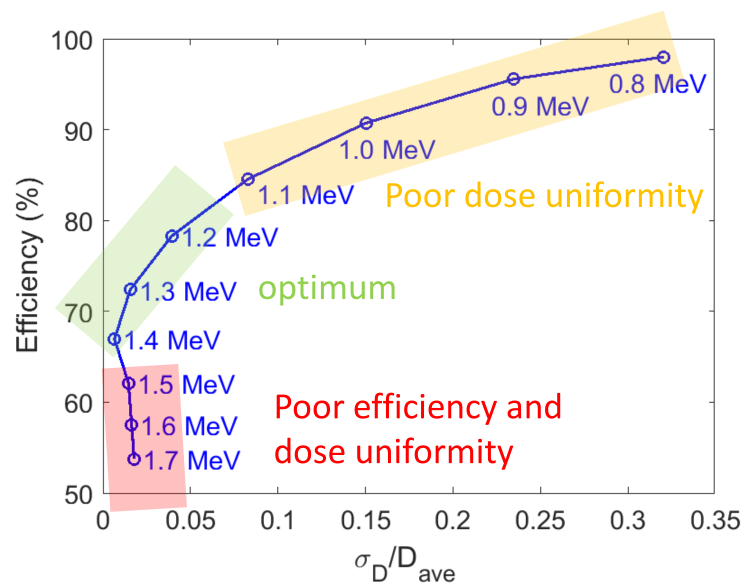




Optimisation of beam parameters

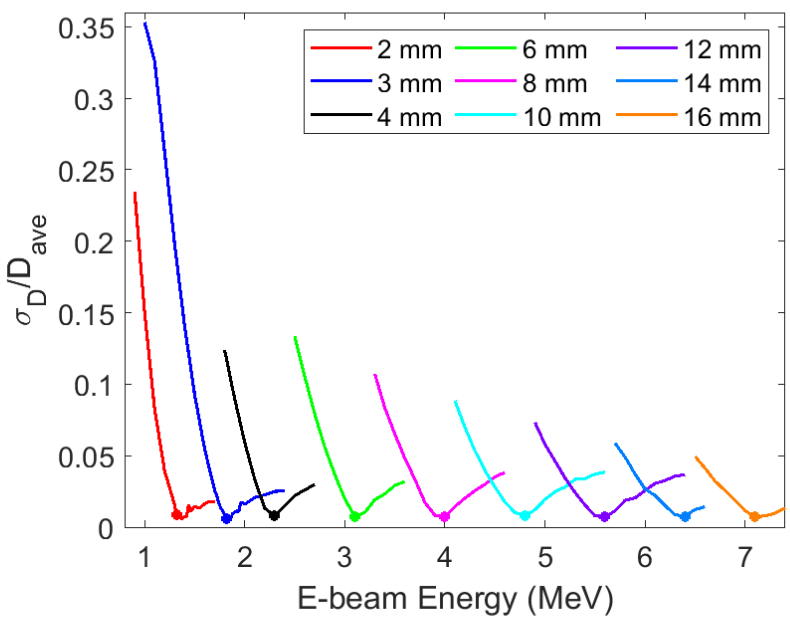
- Simulations in G4Beamline allow us to determine the relationship between dose uniformity and energy deposition efficiency.
- In order to provide comparable throughput to conventional tanning, the beam power deposited in the hide must be constant
  - Higher deposition efficiency can result in a 20 – 30% reduction in beam current

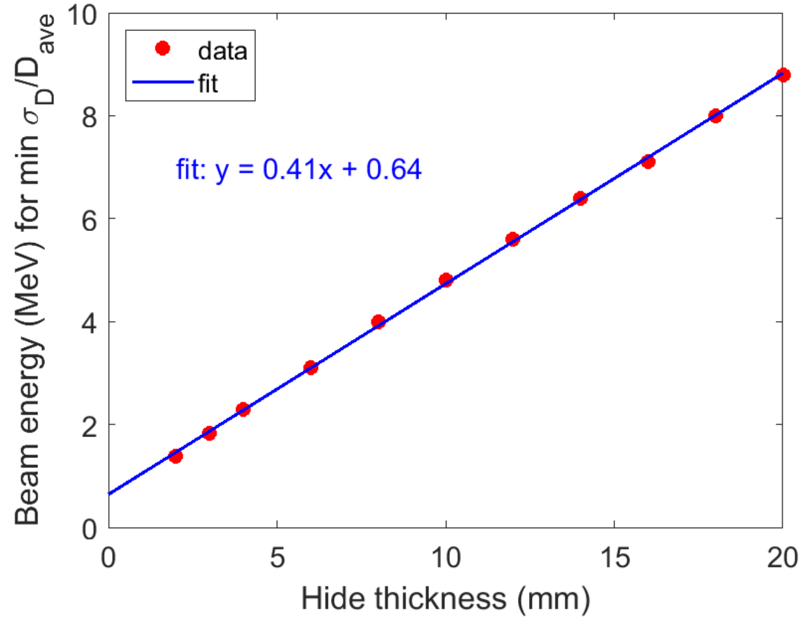




Optimisation of beam parameters

- For different hide thickness, we can optimise the beam energy to ensure a dose uniformity within 1%





Summary

- The leather industry has a global turnover of $250 billion, but has a significant environmental impact due to its resource intensive processes and hazardous effluent produced.
- E-beam tanning is a novel, potentially disruptive technology, which seeks to drastically reduce or eliminate wastewater production.
- Despite relatively high capital costs, higher throughput and lower running costs are expected to outweigh this for medium/large scale tanneries.
- Optimisation of beam parameters can result in high energy deposition efficiency and high dose uniformity.

Thank you!
Questions?