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Suitability of Exergy Analysis for Industrial Energy Efficiency, Manufacturing and Energy Management

Sanober Hassan Khattak, Dr. Richard Greenough, Dr. Neil Brown
De Montfort University of Leicester, UK.

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Scope and Purpose

- Critical analysis of the concept “exergy analysis”.
- Evaluate its value by applying the concept to an energy efficiency comparison study.

What is this “exergy”?
Maybe a spelling mistake?

I think I’ll just stick with energy!

Forget about it!

Do we really need Exergy

- We need to reduce **energy consumption!**
- But Energy is a **conserved quantity!**
- It changes form, and reduces to a less useful form after any real process.

Usefulness of Energy

- This Usefulness of energy = Exergy
- It is this **exergy** that is consumed, not energy!
- We call this usefulness the “quality” of energy.

Need for Exergy

- So , to quantify correctly:
 - Inefficiencies
 - Waste energy
- We need exergy analysis.

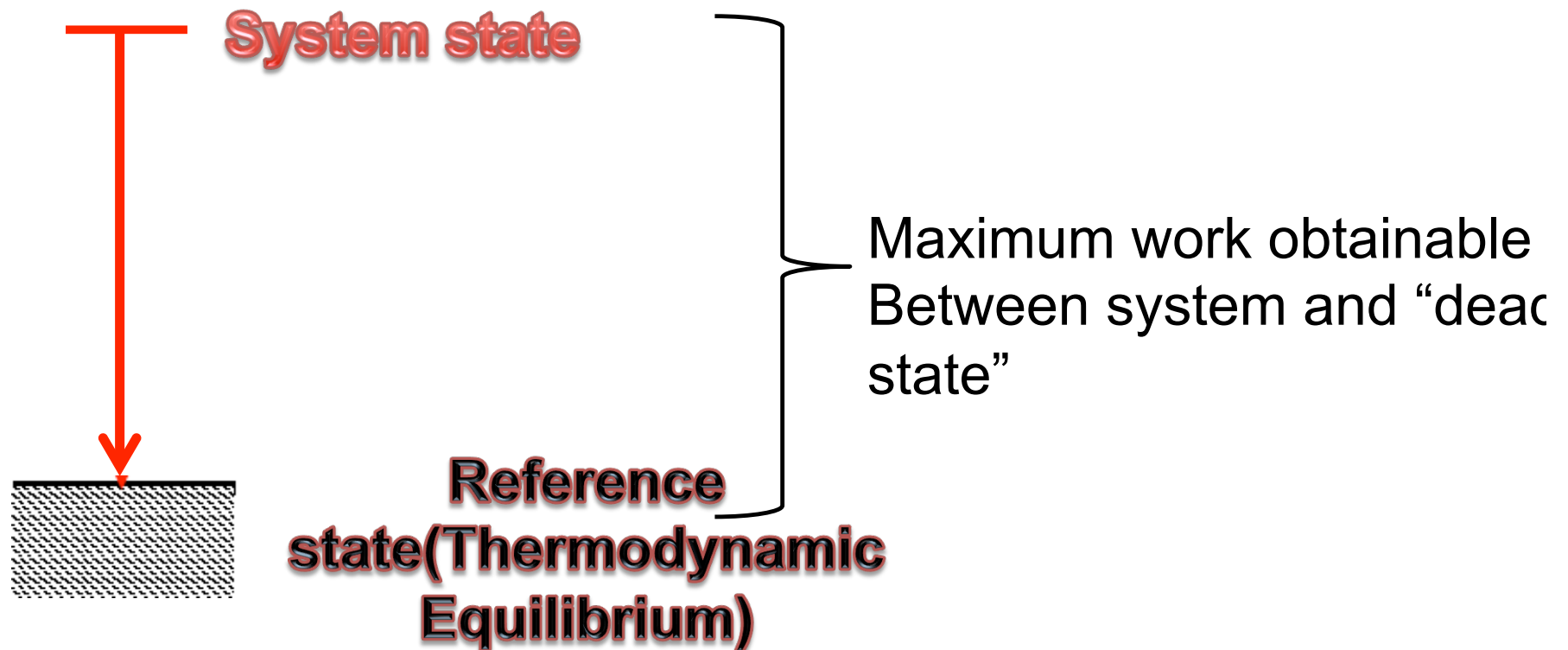
Exergy is back!
Sorry ☹️

What is Exergy

Definition:

- It is the maximum theoretical work obtained when the system is brought into complete thermodynamic equilibrium with the environment.

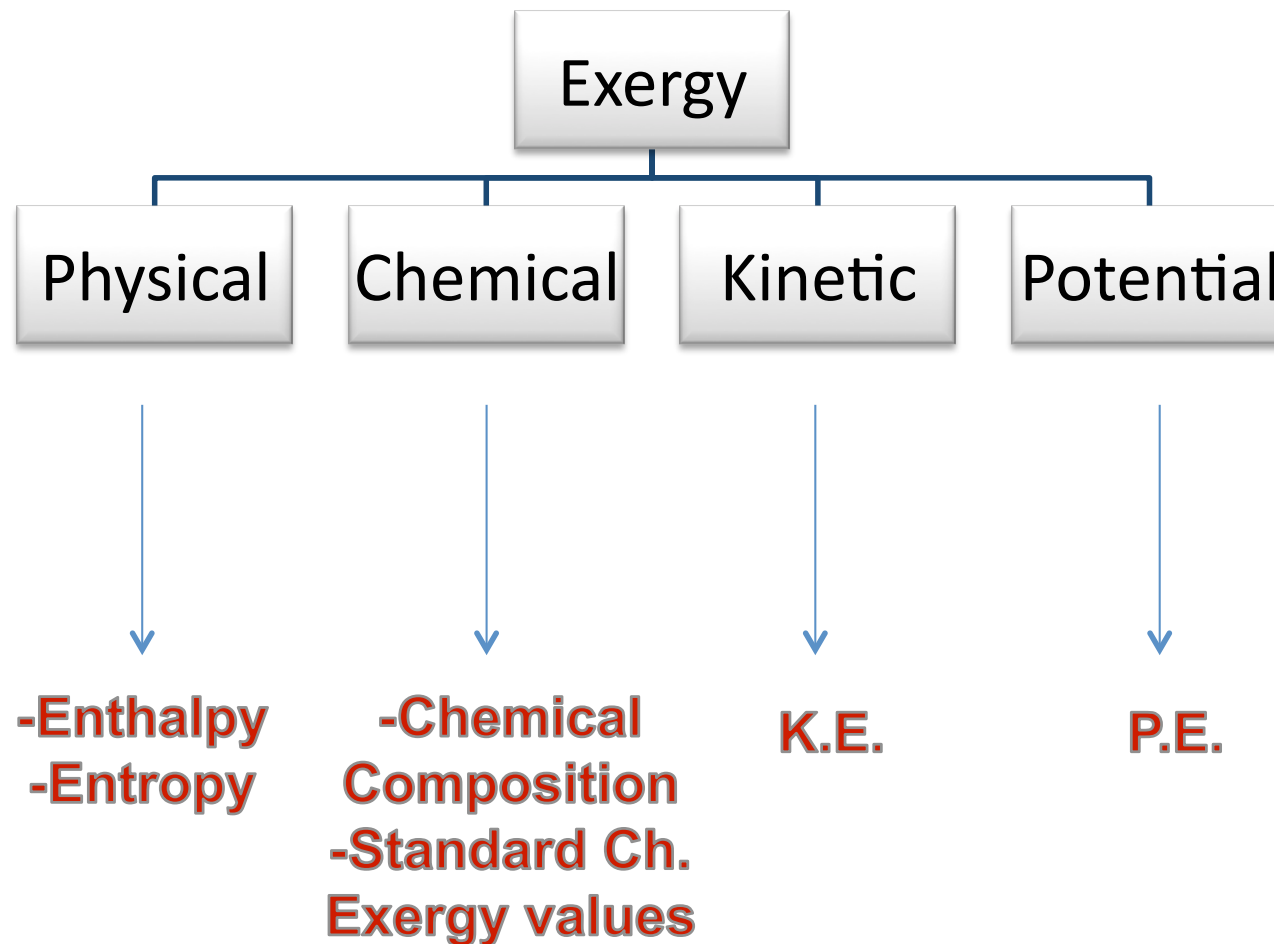
Exergy



Introduction to the “Exergy” concept, 2.813/2.83 T.G. Gutowski, Energy, Material and Manufacturing

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Forms of Exergy Associated with Material Flow

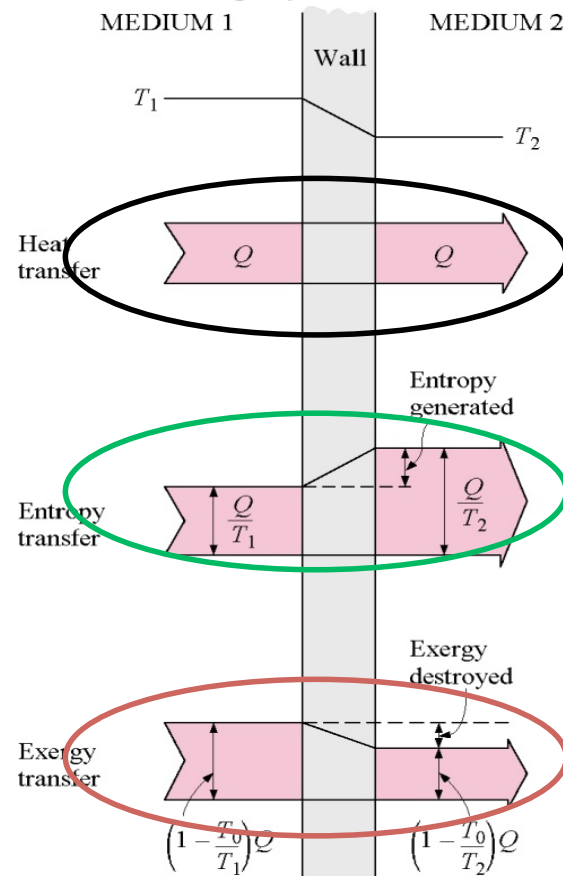


Exergy of an Energy Interaction

- Work Interaction = Exergy

- Heat Interaction = $E_X^Q = Q \left(1 - \frac{T_0}{T} \right)$

Energy and Exergy Consumption!



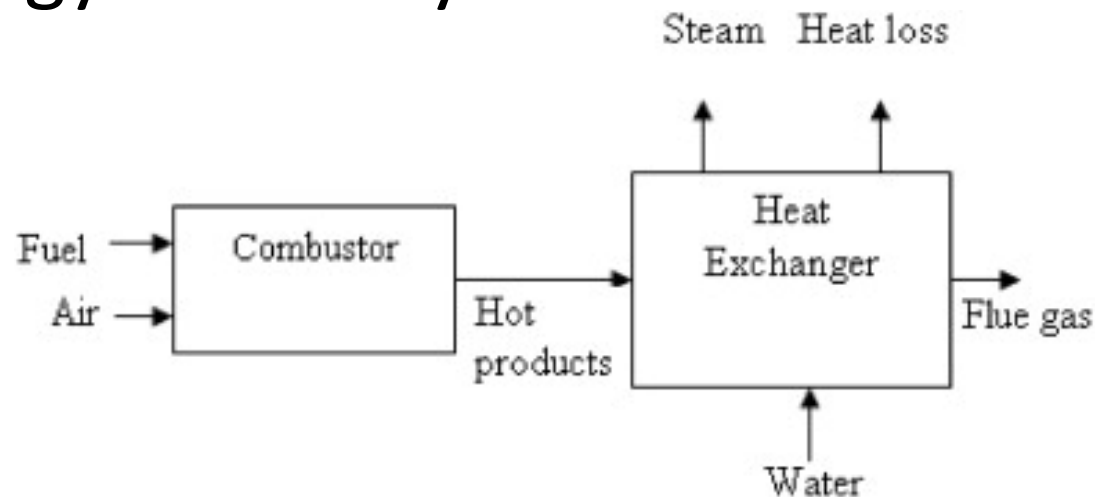
Thermodynamics: An Engineering Approach,
5th edition by Yunus A. Çengel and Michael A. Boles

- Energy remains the same but quality degrades
- Entropy generated
- Exergy “consumed” and indicates loss of quality of the energy

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Merits of exergy analysis

- Identification of inefficiencies
- Exergy efficiency of an Industrial boiler



Changel and Boles, 2006

Results of analysis

	Energy efficiency, η (%)	Exergy efficiency, ψ (%)
Combustor	100	45.18
Heat Exchanger	72.13	48.054
Boiler	72.46	24.89

- Inefficiency identification in power plants

R. Saidur, J.U. Ahamed, H.H. Masjuki, Energy, exergy and economic analysis of industrial boilers, Energy Policy, Volume 38, Issue 5, May 2010

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Exergy and Economics: Is it Profitable?

(M.A. Rosen)

- Exergy rather than energy is of value and it makes sense to base costs and prices on exergy.
- Commodities with high exergy can perform work and help in manufacturing and services. (high quality waste heat)
- Coal power plant : systematic correlation between exergy loss rate and capital cost, but no dependence on energy.

Profitability of Exergy Continued...

- Extends the point to Combined heat and power and Trigeneration plants.
- In a Trigeneration plant, the cooling capacity, a cold product, carries little energy but is a product of value.
- Exergy on the other hand will impart a more realistic value to the hot as well as cold products.

Continued...

- Techniques of economic analysis based on exergy
 - Thermoeconomics
 - Second-Law costing
 - Exergoeconomics
- Sophisticated and powerful techniques, but...

Merits continued...

- A quality control parameter
- Measure of the resource value of material streams
- Comparison of energy efficiency between varied manufacturing designs

De Merits of Exergy analysis

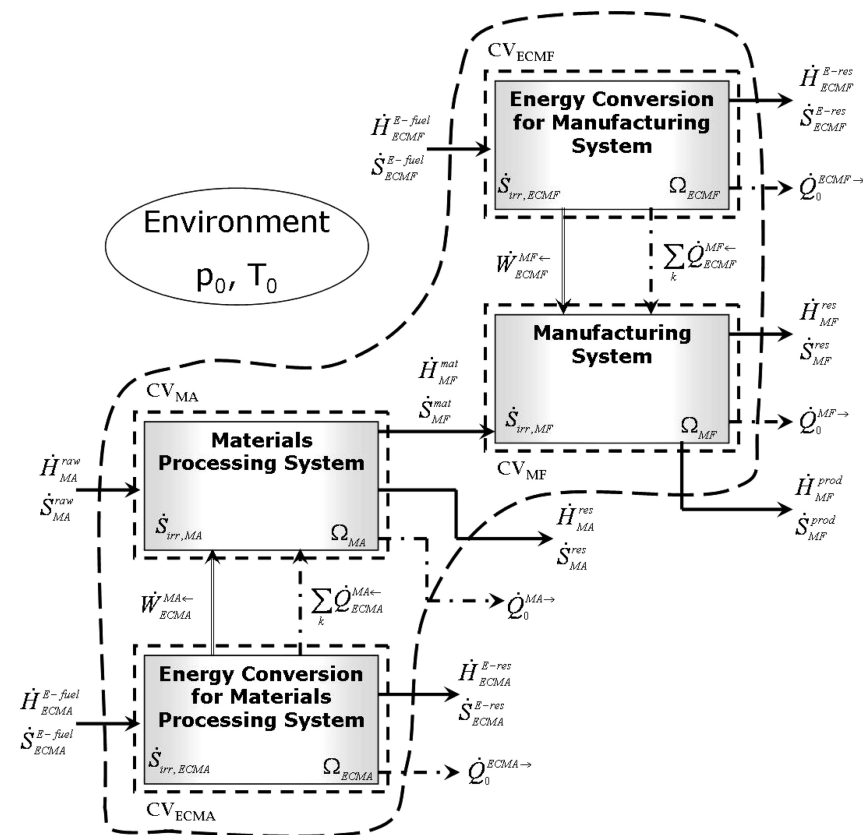
- Some Prominent ones mentioned.
- Resource value of minerals and Impact of waste?
- No robust efficiency definition for manufacturing
- Application complicated!

Application areas

- Varied application areas
 - Sustainability science, Ecosystems analysis, Evolution theory, Social theory and Policy & decision making.
- Common Industrial areas of application
 - Power generation, Thermal systems, steel industry and cement industry.
- Manufacturing
 - Gutowski analysing manufacturing with exergy analysis.

Exergy and manufacturing

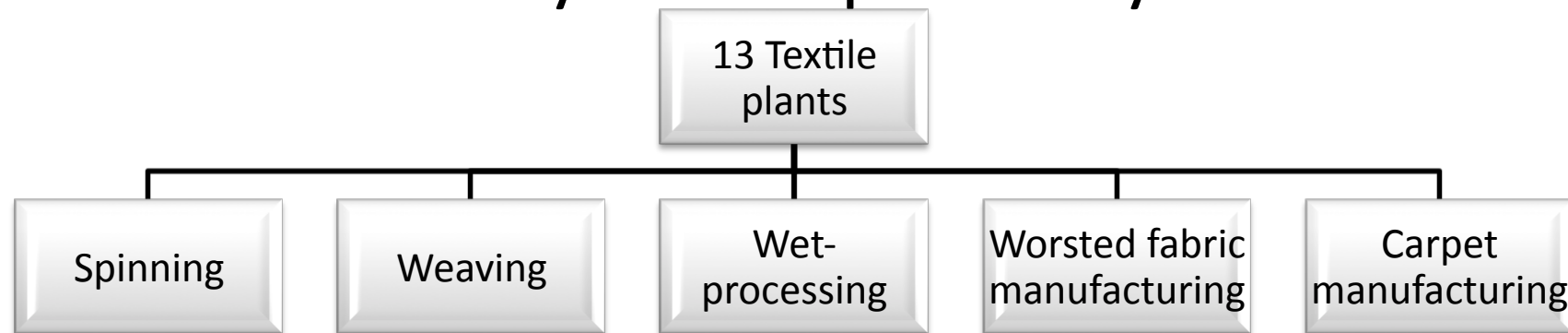
- Modelling of the process as a control volume with mass and energy streams balance
- Mass balance
- Energy balance
- Entropy balance
- Exergy destruction
- Simplifications and assumptions



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Utility of Exergy for Comparison Studies

- 13 textiles plants compared
- Divided on the basis of 5 sub-sectors
- Plant level study with explanatory variables.



Reference : Ali Hasanbeigi, Abdollah Hasanabadi, Mohamad Abdorrazaghi, Comparison analysis of energy intensity for five major sub-sectors of the Textile Industry in Iran, Journal of Cleaner Production, Volume 23, Issue 1

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Results...

Energy intensities for the studied plants in 2003.

Sub-sector	Plant	Electricity intensity (MWh/t)	Fuel intensity (GJ/t)	Total final energy intensity (GJ/t)
Spinning	A	6.6	12.4	36.2
	B	4.7	7.1	24.2
	C	3.6	8.1	21.1
Weaving	D	2.2	17.3	25.2
	E	1.2	10.7	14.9
Wet-processing	F	2.5	112.2	121.2
	G	1.5	84.1	89.5
	H	2.1	40.3	48.0
Worsted fabric	I	22.8	183.3	265.3
	J	19.1	296.8	365.5
	K	20.6	400.0	474.1
	Plant	Electricity intensity (MWh/12 m ² carpet)	Fuel intensity (GJ/12 m ² carpet)	Total final energy intensity (GJ/12 m ² carpet)
Carpet	L	0.2	1.9	2.5
	M	0.1	1.0	1.5

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Continued...

- Weaving

Sub-sector	Plant	Total final energy intensity (GJ/t)
Weaving	D	25.2
	E	14.9

- Is plant E really more efficient?
- Climate affects!

Reference : Ali Hasanbeigi, Abdollah Hasanabadi, Mohamad Abdorrazaghi, Comparison analysis of energy intensity for five major sub-sectors of the Textile Industry in Iran, Journal of Cleaner Production, Volume 23, Issue 1

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Continued...

- A total of 15 explanatory variables identified in study
- Exergy analyses will automatically account for 9!
- Comparison simplified
- Exergy a better indicator than energy in this case

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Is it practical?

- Acquisition of material streams required
- Will the theoretical value of chemical exergy correlate well with experimental values obtained?
- How much instrumentation required?
- Needs to be done....

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Conclusion

- Potentially beneficial
- Characterization of manufacturing processes being evaluated through exergy analysis
- What type of specific benefits can be achieved for each manufacturing process if any.
- Machining?
 - Electricity same in energy and exergy scale.
 - Chemical exergy unchanged.
 - Low grade waste heat.
 - Exergy value of material processed/wasted may be of more value.

Thanks for listening!