TOPIC III - Energy Balances

Steady Flow (Lecture 3/4)

Contents

6. Derivation of an Energy Equation for Steady Flow

Applications (next week)

Turbines, compressors, engines, reciprocating engines

Objectives

Energy balances under “steady conditions”.

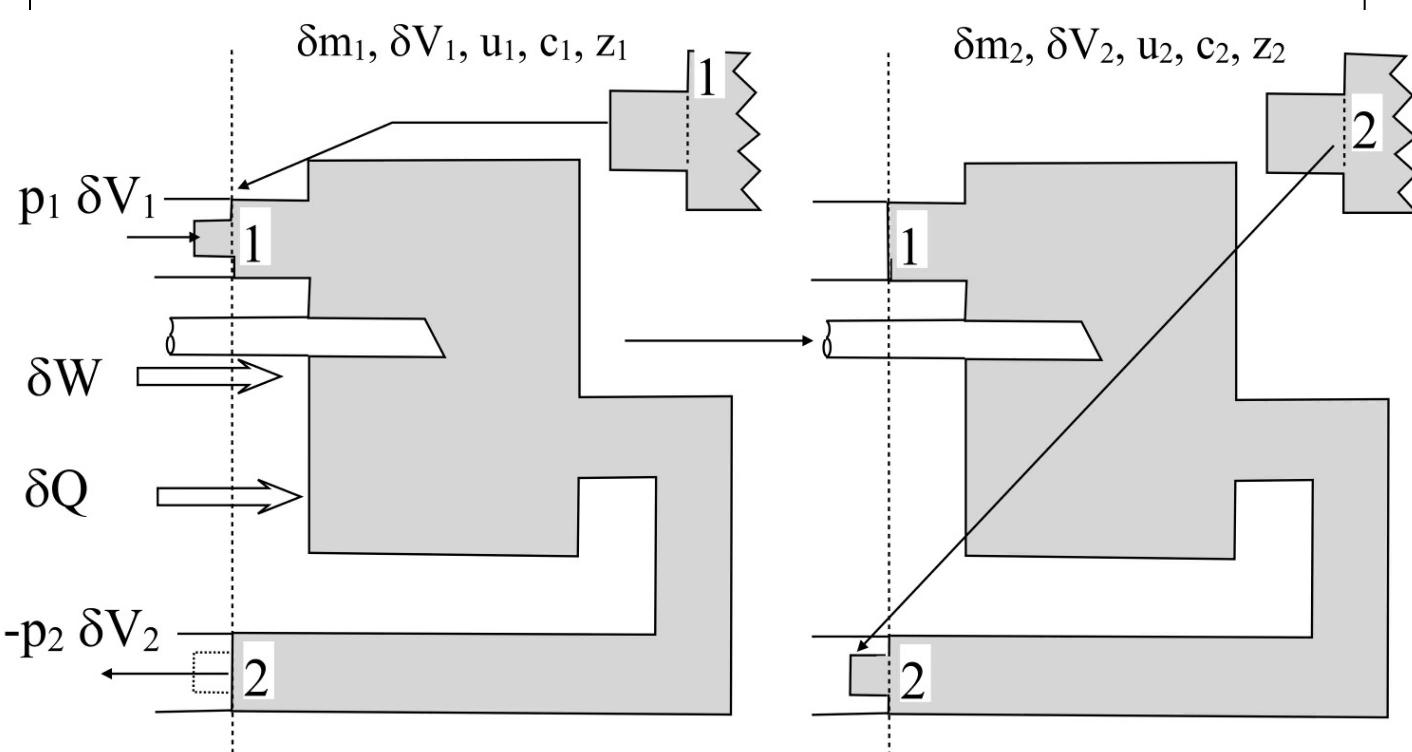
Useful Definition

Flow work (pV) = work to deform part of a boundary displacing volume V at pressure p

TOPIC III - Energy Balances

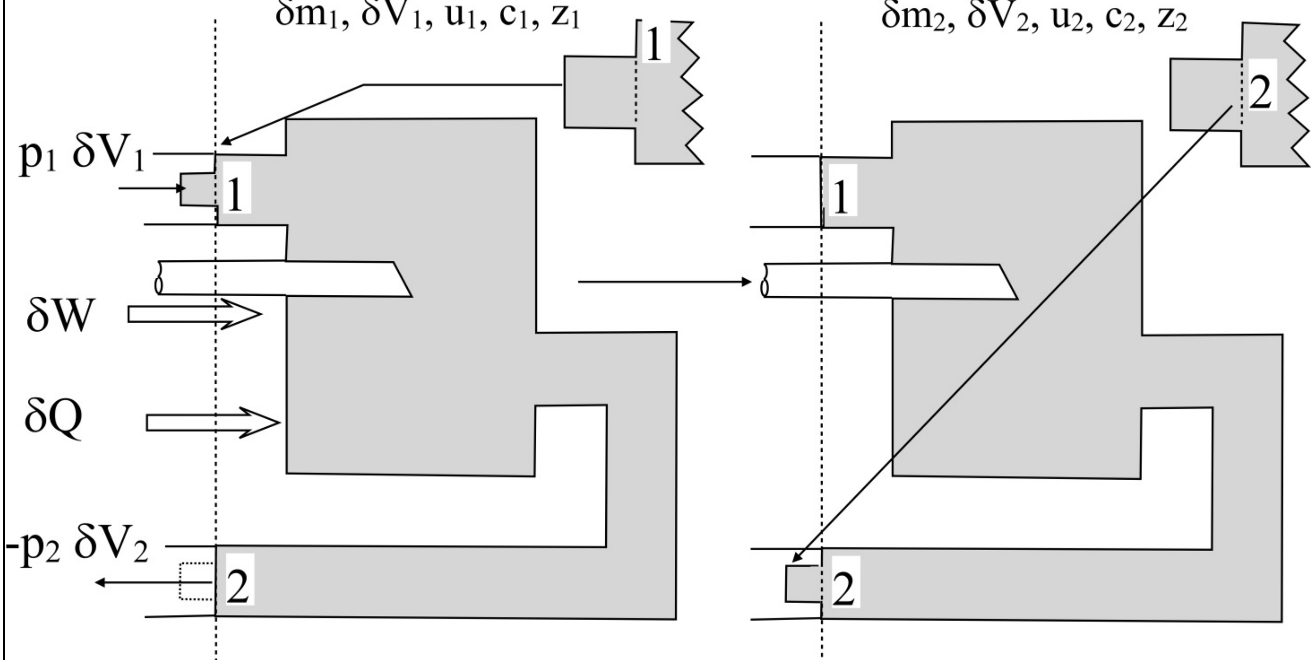
Steady Flow (Lecture 3/4)

- Fluid continuously passes into & away from a system. **An open system**.
- Insignificant time variations => steady flow process
- Reformulation of 1st law +moving boundary
- Mass δm, enters/ leaves plant during δt.
- Energy balance follows. Note "flow work". Boundary moves δm into engine proper
- (also known as displacement work)



TOPIC III - Energy Balances

Steady Flow (Lecture 3/4)



Flow work is

$W_{flow} = p_1 \delta V_1 - p_2 \delta V_2 = \delta m\,(p_1 \mathcal{V}_1 - p_2 \mathcal{V}_2)$

Tabulate

- flow work
- shaft work
- heat addition
- energy in the projections at #1 and #2

TOPIC III - Energy Balances

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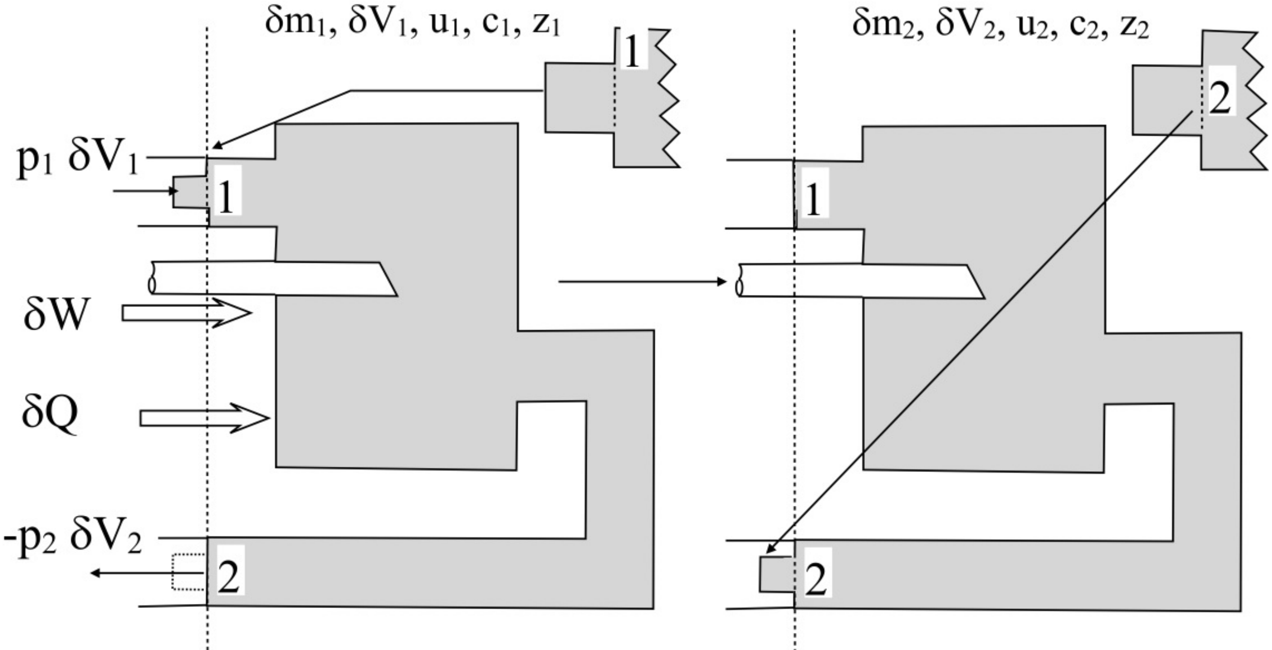

Energy balance

Term	Energy Added	Energy Rejected	
Heat addition	δQ		
Work addition			
Shaft work	δW		
Flow work	$\delta m\ p_1\ v_1$	$\delta m\ p_2\ v_2$	Part of enthalpy
	At start	At end	
Total energy to right of line 1 - 2	E_{12}	E_{12}	No change in steady flow
Energy in δm			
Internal energy	$\delta m\ u_1$	$\delta m\ u_2$	Part of enthalpy
Kinetic energy	$\delta m\ c_1^2/2$	$\delta m\ c_2^2/2$	
Potential energy	$\delta m\ g\ z_1$	$\delta m\ g\ z_2$	

Equate input and output terms. Note specific enthalpy, $h = u + p\,\mathcal{V}$

$$\delta Q + \delta W \;= \ldots$$

$$\delta m[(h_2 + \frac{1}{2}\,c_2^2 + g\,z_2) - (h_1 + \frac{1}{2}\,c_1^2 + g\,z_1)]$$

Divide by time increment.

$$\frac{\delta m}{\delta t} \to \dot{m} \qquad \frac{\delta Q}{\delta t} \to \dot{Q} \qquad \frac{\delta W}{\delta t} \to \dot{W}$$

the dot (•) indicates mass flow rate, heating power and mechanical power

The steady flow energy equation

$$\dot{Q} + \dot{W} \;= \dot{m}[(h_2 + \frac{1}{2}\,c_2^2 + g\,z_2) - (h_1 + \frac{1}{2}\,c_1^2 + g\,z_1)]$$

TOPIC III - Energy Balances

Steady Flow (Lecture 3/4)

Special case – multiple inlets and/ or outlets

$$\sum \dot{Q} + \sum \dot{W} = \sum_{all\ o} \dot{m}_o \left(h_o + \frac{1}{2} c_o^2 + g z_o\right) - \sum_{all\ i} \dot{m}_i \left(h_i + \frac{1}{2} c_i^2 + g z_i\right)$$

[9]

TOPIC III - Energy Balances

Steady Flow (Lecture 3/4)

<u>Conclusions</u>

- Open systems – flow in (and out)
- Steady systems – engines have settled at operating temperature, no change in state of machine
- Internal, kinetic and potential energies are important. Energy is conserved (1st law)
- An additional, complicating term is flow work (or displacement work), $p\mathcal{V}$
- Comparing energy inputs/ outputs over time interval Δt, we derive the steady flow energy eqn (SFEE)
- The u and $p\mathcal{V}$ terms are conveniently added to form specific enthalpy, h (Richard Mollier)

TOPIC III - Energy Balances

Steady Flow (Lecture 3/4)

Table of Energy Balances (as slide 4 but blank)

Term	Energy Added	Energy Rejected	

TOPIC III - Energy Balances

Steady Flow (Lecture 3/4)

Alternative view of moving boundary