ENERGY IN WATER FLOWS ARE

HYDRAULIC HEAD
- KINETIC ENERGY - ENERGY OF MOTION
- POTENTIAL ENERGY - ENERGY OF POSITION
- PRESSURE ENERGY - ENERGY OF "COMPRESSION

- THERMAL ENERGY - THERMAL OSMOTIC POTENTIAL
- CHEMICAL ENERGY - CHEMICAL-OSMOTIC POTENTIAL
- ELECTRICAL ENERGY - ELECTRO-OSMOTIC POTENTIAL

COUPLED-PROCESS THEORY

IN HYDRAULIC ENGINEERING PRIMARILY CONCERNED WITH FIRST THREE ENERGY TYPES

ASIDE:

FLOW	GRADIENT: HYDRAULIC HEAD	ELECTRIC POTENTIAL	TEMP.	CONCENTRATION
FLUID	DARCY; DARCY-WEISBACH	ELECTRO-OSMOSIS; CASAGRANDE	THERMAL OSMOSIS	CHEMICAL OSMOSIS
ELECTRICITY	ROUSS	OHM	SEEBECK; THOMPSON	SEDIMENTATION CURRENT
HEAT	THERMAL FILTRATION	PELTIER	FOURIER	DUFOR
SOLUTES	ULTRA-FILTRATION	ELECTRO-PHORESIS	SORET	FICK

ENERGY FLUX IN $= \int_{①} e\rho(V\cdot n)\,dA$

$e = \dfrac{dE}{dm}$ (ENERGY/UNIT MASS)

ENERGY FLUX OUT $= \int_{②} e\rho(V\cdot n)\,dA$

$$e = \underbrace{\hat{u}}_{\text{INTERNAL}} + \overbrace{\frac{1}{2}V^2}^{\text{KINETIC}} + \underbrace{gz}_{\text{POTENTIAL}}$$

"EQUATION OF STATE" — $\hat{u} = \hat{h} - P/\rho$

ENTHALPY

ENERGY IN C.V. $= \int_{C.V.} e\rho\,d\forall$

ENERGY CONSERVATION:

$$\frac{dQ}{dt} - \frac{dW}{dt} = \frac{\partial}{\partial t}\int_{C.V.} e\rho\,d\forall + \int_{C.S.} e\rho(V\cdot n)\,dA$$

HEAT ADDED <u>TO</u> SYSTEM

WORK DONE <u>BY</u> SYSTEM

$$\frac{dW}{dt} = \frac{dW_{SHAFT}}{dt} + \frac{dW_{PRESS}}{dt} + \frac{dW_{VISCOUS\ STRESS}}{dt}$$

W_{SHAFT} : TURBINE(S) (+ WORK)
PUMP(S) (− WORK)

W_{PRESS} : WORK DONE TO PUSH WATER AGAINST PRESSURE

$W_{VISCOUS\ STRESS}$: SHEAR WORK (USUALLY NEGLIGIBLE)

W_{PRESS} :

$$W = F \cdot x$$

$$\frac{dW}{dt} = F \cdot \underbrace{\frac{dx}{dt}}_{V} \text{ VELOCITY} \qquad : \quad \frac{dW_{PRESS}}{dt} = \int dp \cdot A \cdot V$$

$$\frac{dW}{dt} = \frac{dW_s}{dt} + \int_{C.S.} \frac{p}{\rho} \cdot \rho (V \cdot n)\, dA + \frac{dW_v}{dt}$$

COMBINE

$$\underbrace{\frac{dQ}{dt}}_{\dot{Q}} - \underbrace{\frac{dW_s}{dt}}_{\dot{W}_s} - \underbrace{\frac{dW_v}{dt}}_{\dot{W}_v} = \frac{d}{dt}\int_{CV} e \rho \, d\forall + \int_{CS} \left(e + \frac{p}{\rho}\right) \rho (V \cdot n)\, dA$$

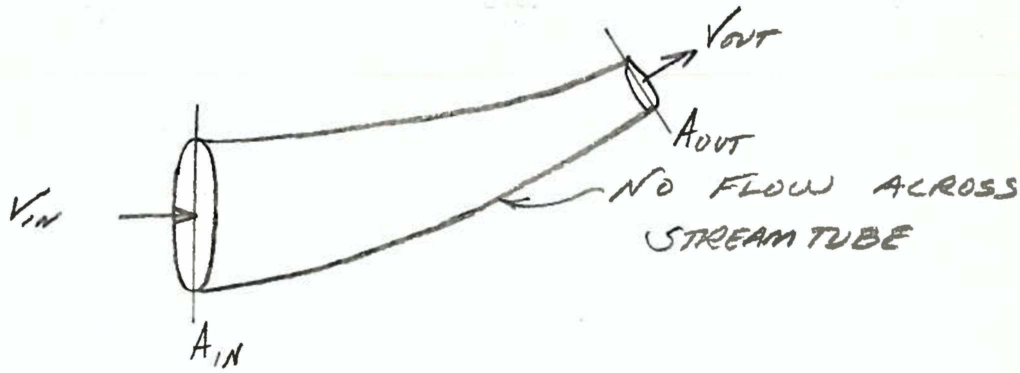
$$\dot{Q} - \dot{W}_s - \dot{W}_v = \frac{d}{dt}\int_{CV} \left(\hat{u} + \frac{1}{2}V^2 + gz\right) \rho \, d\forall$$

$$+ \int_{CS} \left(\hat{h} + \frac{1}{2}V^2 + gz\right) \rho (V \cdot n)\, dA$$

FOR STEADY FLOW THE VOLUME INTEGRAL VANISHES

$$\dot{Q} - \dot{W}_s - \dot{W}_v = \int_{CS} \left(\hat{h} + \frac{1}{2}V^2 + gz\right) \rho (V \cdot n)\, dA$$

ENERGY EQUATION: (STEADY FLOW)
ALONG A STREAMTUBE



$$\dot{Q} - \dot{W}_s - \dot{W}_v = \rho V_{OUT} A_{OUT}\left(\hat{h}_{OUT} + \frac{1}{2}V_{OUT}^2 + g z_{OUT}\right) - \rho V_{IN} A_{IN}\left(\hat{h}_{IN} + \frac{1}{2}V_{IN}^2 + g z_{IN}\right)$$

DIVIDE BY MASS FLUX: ρQ ← DISCHARGE

$$\frac{\dot{Q}}{\rho Q} = \dot{q} \;;\; \frac{\dot{W}_s}{\rho Q} = \dot{w}_s \;\dots$$

$$\dot{q} - \dot{w}_s - \dot{w}_v = \hat{h}_{OUT} + \frac{1}{2}V_{OUT}^2 + g z_{OUT} - \left(\hat{h}_{IN} + \frac{1}{2}V_{IN}^2 + g z_{in}\right)$$

BREAK ENTHALPY & REARRANGE:

$$u_{IN} + \frac{p_{IN}}{\rho} + \frac{1}{2}V_{IN}^2 + g z_{in} = u_{OUT} + \frac{p_{OUT}}{\rho} + \frac{1}{2}V_{OUT}^2 + g z_{OUT} + \dot{w}_s + \dot{w}_v - \dot{q}$$

LET INLET HAVE SUBSCRIPT 1, OUTLET HAVE SUBSCRIPT 2

$$\frac{p_1}{\rho} + \frac{1}{2}V_1^2 + g z_1 = \frac{p_2}{\rho} + \frac{1}{2}V_2^2 + g z_2 + \dot{w}_s + \dot{w}_v - \dot{q} + (\hat{u}_2 - \hat{u}_1)$$

DIVIDE BY g

VISCOUS SHEAR

$$\underbrace{\frac{p_1}{\rho g}+\frac{V_1^2}{2g}+z_1=\frac{p_2}{\rho g}+\frac{V_2^2}{2g}+z_2}_{\text{FRICTIONLESS FLOW BERNOULLI'S EQUATION}}+\underbrace{h_s}_{\text{TURBINE/PUMPING TERM}}+h_v+\underbrace{\frac{(\hat{u}_2-\hat{u}_1-q)}{g}}_{\text{HEAT TRANSFER COMPONENT (FRICTION)}}$$

SUMMARY FOR STEADY PIPE FLOW

1. CONTINUNITY: $A_1V_1=A_2V_2=Q$
2. MOMENTUM: $\Sigma\vec{F}=\rho Q(\vec{V}_2-\vec{V}_1)$
3. ENERGY: $\frac{p_1}{\gamma}+\frac{V_1^2}{2g}+z_1=\frac{p_2}{\gamma}+\frac{V_2^2}{2g}+z_2+h_s+\underbrace{h_F}_{\text{FRICTION: "HEAT TRANSFER"}}$

FOR MOST PROBLEMS WE WILL SIMPLIFY THE ENERGY EQUATION BY ASSUMING ISO-THERMAL PROCESSES

1. $A_1V_1=A_2V_2=Q$
2. $\Sigma\vec{F}=\rho Q(\vec{V}_2-\vec{V}_1)$
3. $\frac{p_1}{\gamma}+\frac{V_1^2}{2g}+z_1+h_P=\frac{p_2}{\gamma}+\frac{V_2^2}{2g}+z_2+h_T+h_F$

h_P: HEAD ADDED BY PUMP

h_T: HEAD REMOVED BY TURBINE

h_F: HEAD REMOVED BY FRICTION