Pi (π) Day with the American Institute of Chemical Engineers

By: Joseph Yurko

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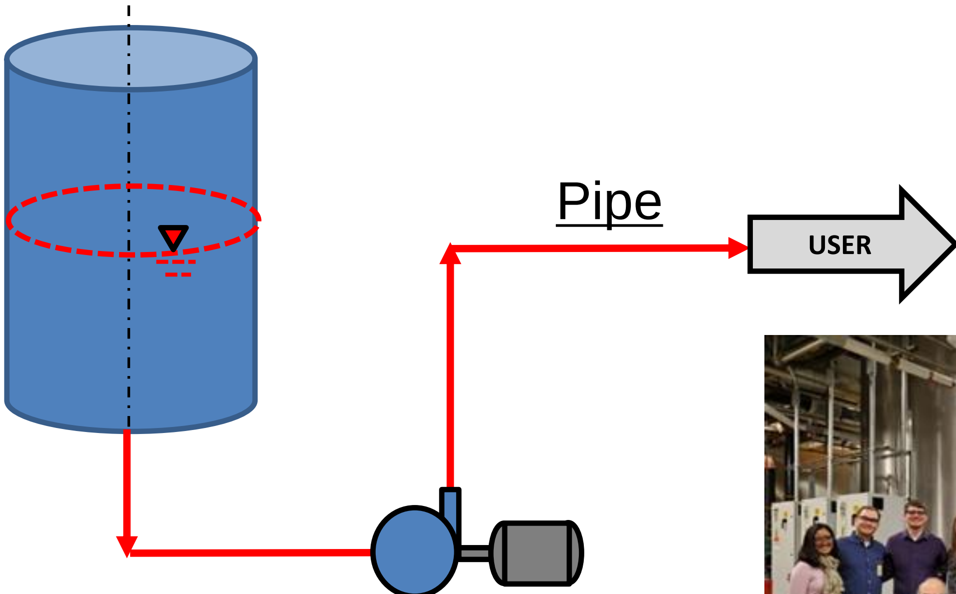
Pi Day with AIChE

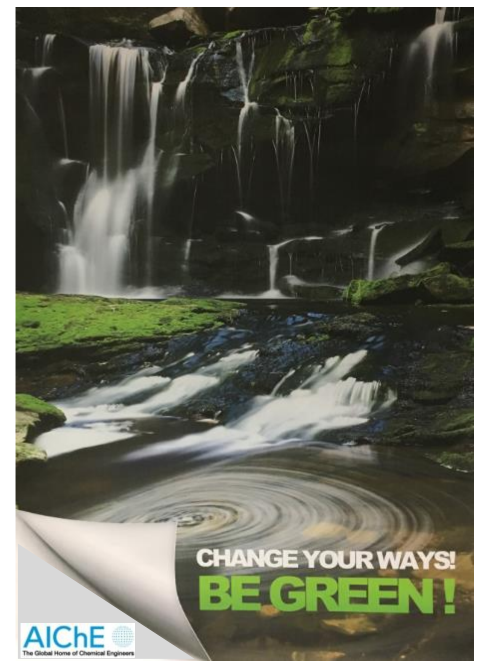
Using Pi (π) to calculate the Energy to Pump a Fluid in a Pipe, and the Carbon Footprint of the Pumping Energy comparing different pipe sizes.



Pump & Motor

Energy to Pump Fluid in Pipe

CWRU Capstone Project Spring Semester 2020



Carbon Footprint of Pumping Energy

Pi Day with AIChE

AIChE The Global Home of Chemical Engineers

Pharmaceutical Production Facility: Where Pi is Applied

How Pi (π) is used in our Energy Calculations with Fluid Hydraulic Pump Head

Needed to calculate the optimum pump size:

- The pipe inside diameter (d)
- The pipe length (L)
- The installed pipe cost per foot ($/ft)
- The fluid and flow rate (gpm)
- The fluid density (ro) and viscosity (cP)
- The pump cost ($) and efficiency (ep)
- The pump motor cost ($) and efficiency (em)
- The sustainable engineering Life Cycle cost of electricity per pound of Carbon Dioxide

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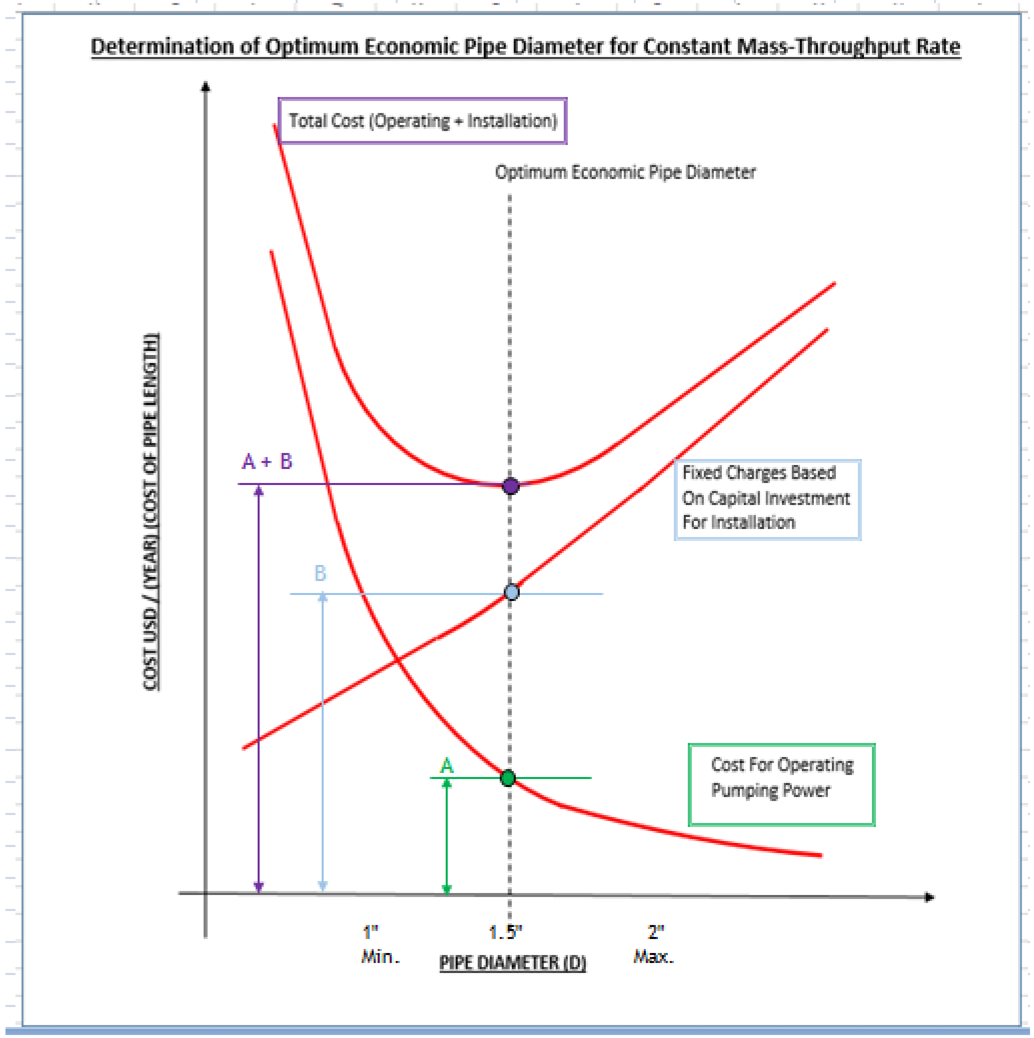
NOTE: Pi = π = 3.1416...

How to calculate the Optimum Pipe Size (Min. – Max.):

- Trial & Error Technique
- Bisection Method
- Based on Flow Rate (gpm)
- First Try Minimum Dia. (1")
- Secondly Try Maximum Dia. (2")
- Select Value in between (1.5")



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How Pi (π) is used in our Energy Calculations with Fluid Hydraulic Pump Head

Pipe Fluid Flow Velocity	Formula		Run # 1	Run # 2	Run # 3	Run # 1	Run # 2	Run # 3	Units
Flow Rate (Q) =		(GIVEN)	30	30	30	0.0668	0.0668	0.0668	Cu Ft / Sec
Inside Pipe Diameter (d) =		(GIVEN)	1	2	1.5	0.0833	0.1667	0.1250	Ft
Pipe Installed Cost/Foot =		(GIVEN)	$15.00	$30.00	$22.50				$ / Ft
Pipe Equivalent Length =		(GIVEN)				1,000	1,000	1,000	Ft
Pipe Cost (estimated) =		(GIVEN)				$15,000	$30,000	$22,500	$
Velocity (v) =	Q * 4 / π D^2	(FIND)				12.2	3.1	5.4	Ft / Sec
Density (ro) =		(GIVEN)				62.4	62.4	62.4	Lbs / Cu Ft
Viscosity (cP) =		(GIVEN)				1	1	1	cP
Reynolds Number(Nre)=	Lbs / Cu Ft · Cu Ft * 4 / π D^2 · D / Viscosity	(FIND)				9.46E+04	5.91E+03	1.87E+04	N/A
Specific Gravity (SG) =		(GIVEN)				1.00E+00	1.00E+00	1.00E+00	N/A
Friction Factor (f) =	1.8 LOG Nre / 7 ^(-2)	(FIND)				0.1055	0.2101	0.1533	N/A
Pressure Drop (Ft/1,000')=	0.0311 f 1,000' Q^2 / d^5	(FIND)				2952.4	183.8	565.1	Ft/1,000
Pump Efficiency (ep)=		(GIVEN)				0.70	0.70	0.70	N/A
Pump Brake Horsepower (BHp) =	Q*Ft*SG / 3,960/ep =	(FIND)				32.0	2.0	6.1	BHp
Motor Efficiency (em) =		(GIVEN)				0.65	0.65	0.65	N/A
Pump Motor Horsepower (MHp) =	BHp / em =	(FIND)				49.2	3.1	9.4	MHp
Pump Motor Horsepower (MHp) =	BHp / em =	(TABLE)				50	5	10	MHp
Pump Motor Horsepower (MHp) =	MHp * 745.7 Watts/Hp	(FIND)				36,657	2,282	7,016	Watts
Pump Motor Cost ($ estimated) =	$ =	(TABLE)				$20,000	$2,000	$4,000	$

STANDARD PUMP MOTOR HORSEPOWER & COST (estimated) TABLE

0.25 Hp	$100	3 Hp	$1,200	25 Hp	$10,000	100 Hp	$40,000
0.5 Hp	$200	5 Hp	$2,000	30 Hp	$12,000	125 Hp	$50,000
0.75 Hp	$300	7.5 Hp	$3,000	40 Hp	$16,000	150 Hp	$60,000
1 Hp	$400	10 Hp	$4,000	50 Hp	$20,000	200 Hp	$80,000
1.5 Hp	$600	15 Hp	$6,000	60 Hp	$24,000	250 Hp	$100,000
2 Hp	$800	20 Hp	$8,000	75 Hp	$30,000	300 Hp	$120,000

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Pharmaceutical Production Facility: Where Pi is Applied

How Pi (π) is used in our Energy Calculations to generate a Carbon Footprint

Sustainable Engineering, Principles and Practices, Dr. Bakshi, Cambridge University Press, 2019

Chapter 9, Inventory Analysis

Table 9.2, Typical Life Cycle Inventory Data from Input-Output Models

Reference: Y. Yang, W.W. Ingwersen, T.R. Hawkins, M. Srocka, and D.E. Meyer;
USEEIO: A New and Transparent United States Environmentally Extended Input-Output model, *Journal of Cleaner Production*, 158: 308-318, 2017

Flow	Units	Reference	Electricity
CO2	kg / $	221100	6.27E+00

HIGH Run # 1 INPUT OUTPUT	LOW Run # 2 INPUT OUTPUT	MIDPOINT Run # 3 INPUT OUTPUT	
36,657	2,282	7,016	Watts
1	1	1	Hours
36,657	2,282	7,016	Wh
36.7	2.3	7.0	kWh

The Bedford Industrial Cost of Electricity is $0.07 kWh

Determine the Life Cycle of CO2 emissions for this system based on an Input-Output model

IO Model Life Cycle CO2 Emissions =

Run # 1 =	6.27E+00	kg / $	$0.07 / kWh	36.7	kWh =	16.1	kg CO2 =	35.4	Lbs CO2
Run # 2 =	6.27E+00	kg / $	$0.07 / kWh	2.3	kWh =	1.0	kg CO2 =	2.2	Lbs CO2
Run # 3 =	6.27E+00	kg / $	$0.07 / kWh	7.0	kWh =	3.1	kg CO2 =	6.8	Lbs CO2

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			Run # 1	Run # 2	Run # 3	
			1" Dia. Min.	2" Dia. Max.	1.5" Dia.	
System Installed & Operating Cost =	$ =	(FIND)	$37,566	$32,160	$26,991	$
System Carbon Footprint (CFP) =	Lbs CO2 / 1,000 Hr =	(FIND)	35	2	7	CFP
Most Sustainable (OPTIMUM) =		(FIND)	HighCO2	High $	Yes, CO2-$	

Using Pi (π) we found our Energy Calculations to generate :

1. Optimum Pipe Diameter of 1.5"
2. Pump Motor Size of 10 Hp
3. Carbon Footprint of 7 Lbs of CO2 per 1,000 hours of running time.

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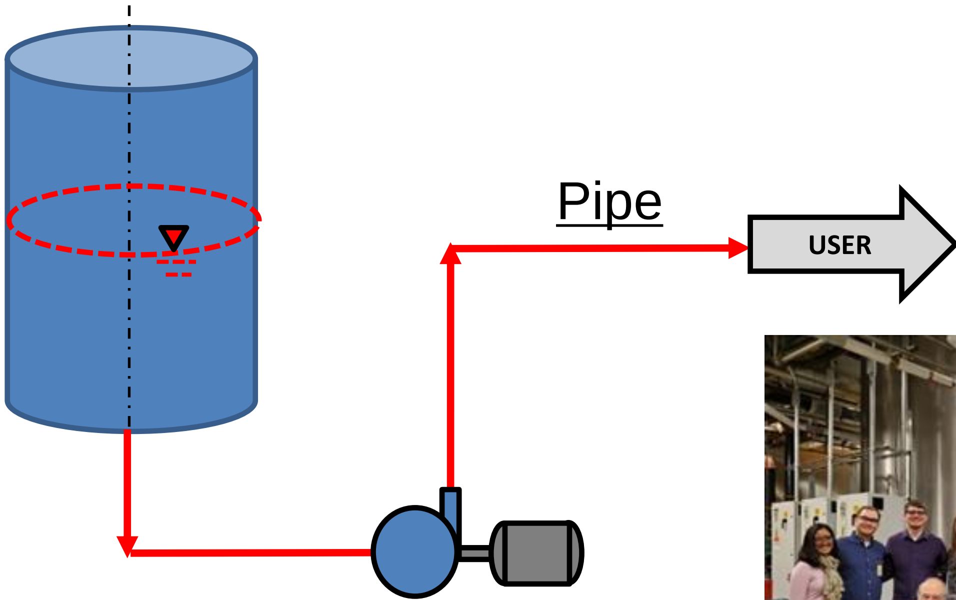

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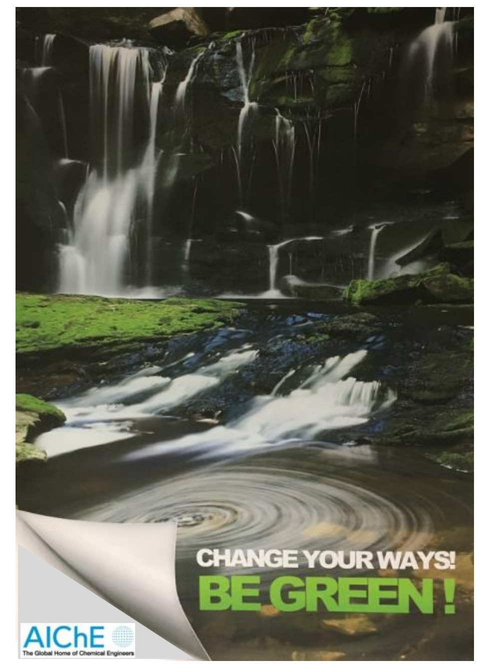

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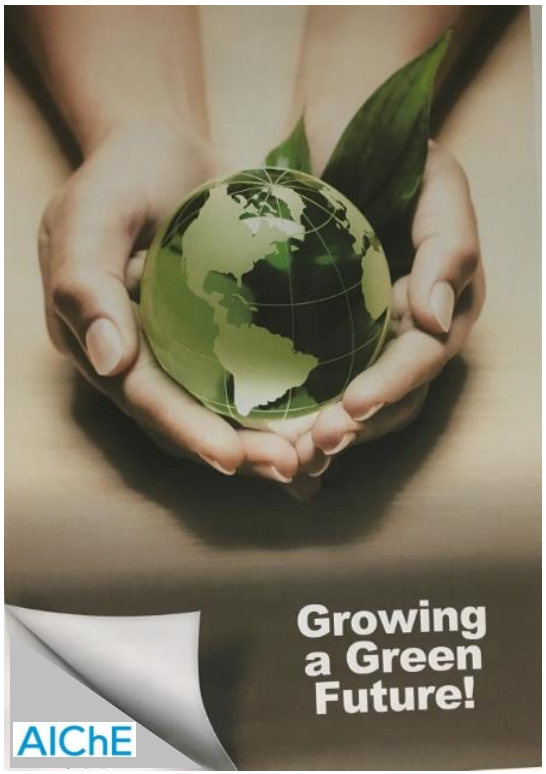

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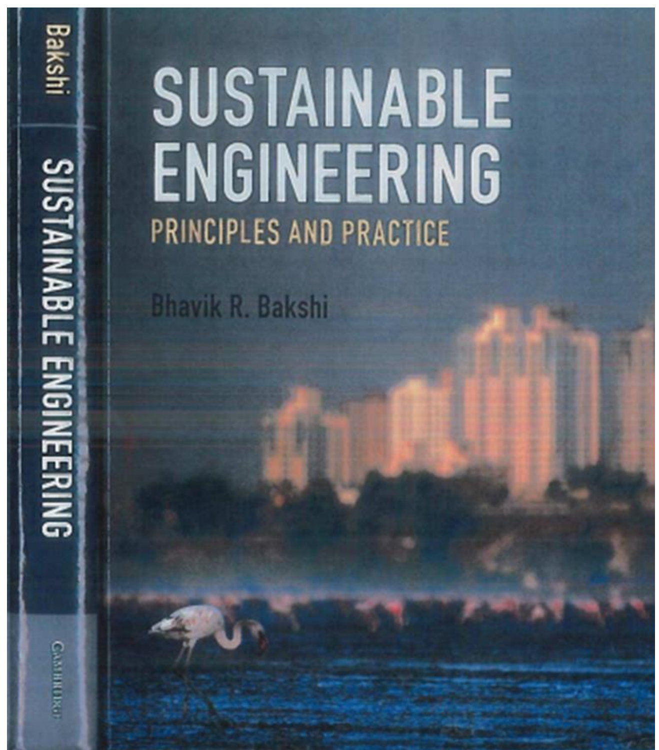

Joseph Yurko, P.E. Background:

Process Consultant with JAY of Northeast Ohio, LLC

- Xellia Pharmaceuticals USA, LLC (Novo Nordisk S/A), Cleveland, Ohio
- Kraft-Heinz Company, Frozen Foods Division, Massilon, Ohio
- Ben Venue Laboratories, Inc. (Boehringer-Ingelheim GmbH), Cleveland, Ohio
- Morrison Knudsen Corporation, Cleveland, Ohio

Licensed Professional Engineer

Emeritus member and Fellow of AIChE

Member of ACS, NSPE, and ISPE

Cleveland State University, Fenn College of Engineering

- Bachelor of Chemical Engineering
- Bachelor of Engineering Science
    - Distinction in Bioengineering