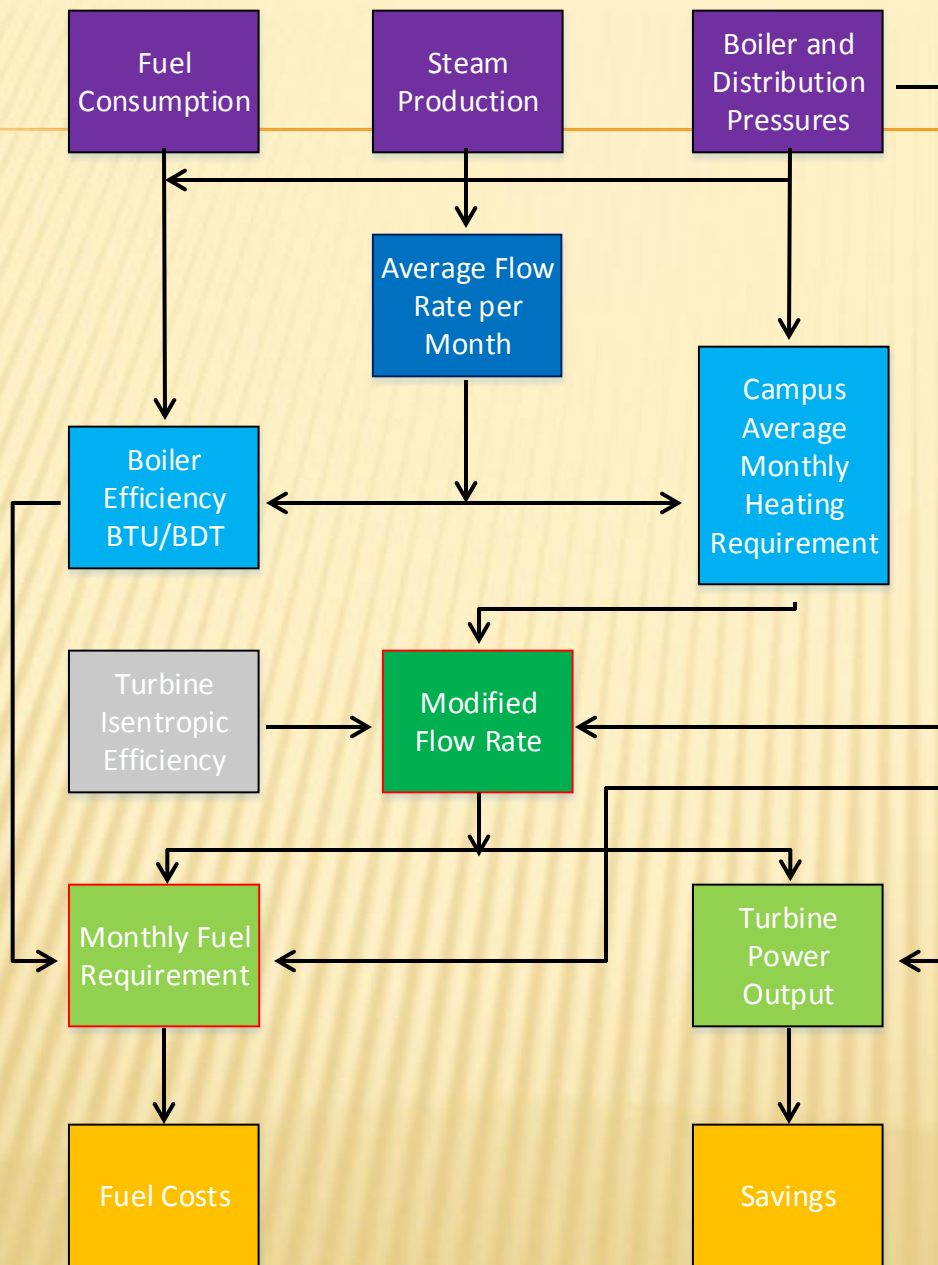


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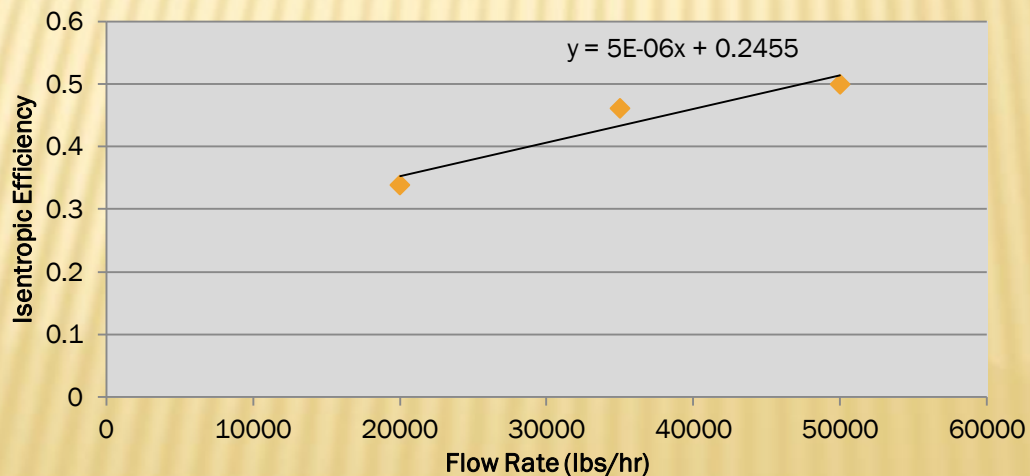
# Data Validation



Montana Validation

# Iisentropic Efficiency

703E						
Iisentropic Efficiency vs. Flow (Manufacturer Provided)						
	Power (hp)	Flow Rate (lbm/hr)	Exhaust Enthalpy (Btu/lb)	Entrance Enthalpy (Btu/lbm)	Iisentropic Exhaust Enthalpy (Btu/lbm)	Iisentropic Efficiency
Max	1187	50000	1140	1200	1079	0.499
Average	767	35000	1144	1200	1079	0.461
Min	322	20000	1159	1200	1079	0.338



Return

# Campus Heating Requirement

$$CHR = \dot{m} \times (h_{boiler\ exit} - h_{condensate\ tank})$$

- CHR = Campus heating requirement (Btu/hr)
- $\dot{m}$  = mass flow rate of steam (lbs/hr)
- $h_{boiler\ exit}$  = Enthalpy of steam exiting boiler (1,195 Btu/lbm)
- $h_{condensate}$  = Enthalpy of condensate returning from campus (180.1 Btu/lbm)

Month	Campus Heating Requirement (Btu/hr)
January	4.65E+07
February	3.99E+07
March	3.52E+07
April	3.12E+07
May	2.29E+07
June	1.69E+07
July	2.23E+07
August	2.41E+07
September	1.96E+07
October	2.82E+07
November	3.64E+07
December	4.25E+07

Return

# Boiler Efficiency (Btu/BDT)

$$BTU/BDT = (\dot{m} \times (h_{boiler\ exit} - h_{boiler\ entry}))/\text{Fuel Input}$$

Month	Btus/BDT (by month)
January	12700000.000
February	12460000.000
March	13090000.000
April	12340000.000
May	13970000.000
June	9830000.000
July	12570000.000
August	13070000.000
September	15840000.000
October	13760000.000
November	12110000.000
December	13240000.000

- BTU/BDT = Campus heating requirement (Btu/hr)
- $\dot{m}$  = mass flow rate of steam **produced by biomass** (lbs/hr)
- $h_{boiler\ exit}$  = Enthalpy of steam exiting boiler (1,195 Btu/lbm)
- $h_{condensate}$  = Enthalpy of condensate entering boiler (199 Btu/lbm)

Return

# Average Flow Rate Per Month

date	LOADS	CEDAR	STEAM BY	STEAM BY	GAS	TOTAL
	DELIVERED	DELIVERED	WOOD	GAS	USAGE	STEAM
1/1/2013	4	50.16	1,234,000	0	0	1,234,000
1/2/2013	8	109.70	1,271,000	0	69	1,271,000
1/3/2013	11	135.47	1,170,000	90,000	1,226	1,260,000
1/4/2013	10	129.30	1,065,000	32,000	467	1,097,000
1/5/2013	5	62.29	1,099,000	0	0	1,099,000
1/6/2013	0	0.00	1,075,000	0	0	1,075,000
1/7/2013	10	115.59	1,022,000	0	0	1,022,000
1/8/2013	7	87.23	946,000	0	0	946,000
1/9/2013	7	100.69	967,000	0	0	967,000
1/10/2013	7	98.56	1,150,000	30,000	445	1,180,000
1/11/2013	5	63.20	1,244,000	0	103	1,244,000
1/12/2013	3	31.64	1,269,000	0	57	1,269,000
1/13/2013	8	101.82	1,303,000	0	0	1,303,000
1/14/2013	11	124.95	1,176,000	90,000	1,249	1,266,000
1/15/2013	12	163.74	1,104,000	90,000	1,239	1,194,000
1/16/2013	6	67.50	646,675	600,000	7,463	1,246,675
1/17/2013	4	52.36	412,429	887,000	11,281	1,299,429
1/18/2013	2	23.38	1,029,000	13,000	159	1,042,000
1/19/2013	7	91.73	1,079,000	0	0	1,079,000
1/20/2013	0	0.00	1,099,000	0	0	1,099,000
1/21/2013	7	101.77	1,151,000	33,000	441	1,184,000
1/22/2013	7	96.98	1,123,000	0	0	1,123,000
1/23/2013	7	106.31	1,014,000	0	0	1,014,000
1/24/2013	8	111.64	918,000	0	0	918,000
1/25/2013	6	81.97	1,061,790	0	0	1,061,790
1/26/2013	4	61.20	917,000	0	0	917,000
1/27/2013	0	0.00	998,000	0	0	998,000
1/28/2013	5	67.73	1,036,000	0	0	1,036,000
1/29/2013	9	123.06	991,000	0	0	991,000
1/30/2013	6	82.28	873,000	14,000	212	887,000
1/31/2013	8	89.63	866,000	0	0	866,000
Jan Totals	194	2531.88	32,309,894	1,879,000	24,411	34,188,894
		<b>Average:</b>	<b>1042255</b>	<b>60613</b>		
		<b>Flow Rate:</b>	<b>43427</b>	<b>2526</b>		

Return

# Monthly Fuel Requirement

$$\text{Biomass Fuel Requirement} = ((\dot{m} \times (h_{\text{boiler exit}} - h_{\text{boiler entry}})) / (\text{Btus/BDT})) \times FR \times MOH$$

Fuel Requirement	=	BDTs of fuel
$\dot{m}$	=	total mass flow rate of steam (lbs/hr)
$h_{\text{boiler exit}}$	=	Enthalpy of steam exiting boiler (1,195 Btu/lbm)
$h_{\text{boiler entry}}$	=	Enthalpy of condensate entering boiler (199 Btu/lbm)
Btus/BDT	=	See 'Boiler Efficiency'
FR	=	Ratio of biomass to natural gas used by month

\* $(1 - FCR) \times \dot{m}$  will yield the quantity of steam produced by natural gas for each month. Then, the Fuel Cost Ratio in the following table can be used to determine the cost of natural gas.

# Monthly Fuel Requirement

January			
STEAM BY WOOD	Cost	STEAM BY GAS	COST
32,309,894	\$134,189.64	1,879,000	\$13,426.05
		FCR	1.72

$$\text{Fuel Cost Ratio} = \frac{\text{Cost of NG} \times \text{Steam by Wood}}{\text{Cost of Biomass} \times \text{Steam by NG}}$$

Month	Fuel ratio	Fuel cost ratio NG/BDT
January	0.945	1.7204
February	0	0
March	0.9366	1.9872
April	0.9597	2.2478
May	0.9305	2.5462
June	0.9098	1.834
July	0.967	1.9719
August	0.9994	2.0267
September	0.9975	3.0091
October	0.8808	1.7595
November	0.9366	1.5935
December	0.9642	2.1314

Return



# Modified Flow Rate

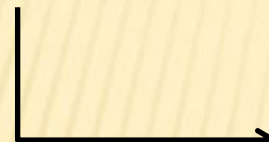
$$\dot{m} = \frac{CHR}{h_{\text{turbine exit}} - h_{\text{condensate tank}}}$$

CHR	=	Campus heating requirement (Btu/hr)
$\dot{m}$	=	Flow rate adjusted for turbine (lbs/hr)
$h_{\text{turbine exit}}$	=	Enthalpy of steam exiting turbine (1,130-1,160 Btu/lbm)
$h_{\text{boiler entry}}$	=	Enthalpy of condensate tank(180.1 Btu/lbm)

\*In developing the value of  $h_{\text{turbine exit}}$  an isentropic efficiency of 65% was used. The resulting modified flow rate was then used to recalculate a new isentropic efficiency for each month. The new isentropic efficiency was in turn used to generate a new flow rate. In other words, an iteration process was used to obtain the actual flow rate.

# Turbine Power Output

$$\eta_{i.e.} = \frac{h_{\text{entry}} - h_{\text{exit,actual}}}{h_{\text{entry}} - h_{\text{exit,isentropic}}}$$


$$h_{\text{exit,actual}} = -\left(\frac{\eta_{i.e.}}{h_{\text{entry}} - h_{\text{exit,isentropic}}} - h_{\text{entry}}\right)$$

$$\text{Power} = \dot{m} \times (h_{\text{turbine entry}} - h_{\text{turbine exit}}) \times \text{Conversion factor} \left(\frac{\text{Btu}}{\text{hr}} \text{ to kW}\right)$$

Return

# Turbine Power Output

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Turbine Power Out (kW)		
	703E	K Frame
January	855	1022
February	677	831
March	564	705
April	474	604
May	309	411
June	208	287
July	298	398
August	332	439
September	252	341
October	411	532
November	591	736
December	746	905

Return

# Fuel Costs

Client Supplied Data					
Month	BDT Fuel Usage	BDT Fuel Cost	Natural Gas Usage (therms)	Natural Gas Fuel Cost	Total Fuel Costs
January	2531.88	\$134,190.00	24411	\$13,426.00	\$147,615.64
February	2113.1	\$109,881.00	0	\$0.00	\$111,994.30
March	1839.02	\$93,790.00	21044	\$12,626.00	\$110,094.06
April	1716.87	\$87,560.00	13766	\$8,260.00	\$99,254.11
May	1140.19	\$58,150.00	18445	\$11,067.00	\$71,497.07
June	426.65	\$21,759.00	95786	\$57,472.00	\$80,084.45
July	1250.34	\$63,767.00	7144	\$4,286.00	\$70,554.02
August	1349.31	\$68,815.00	131	\$79.00	\$71,592.43
September	869.87	\$53,062.00	671	\$403.00	\$46,506.11
October	1313.17	\$80,103.00	31792	\$19,075.00	\$88,673.01
November	1985.62	\$121,123.00	21759	\$13,055.00	\$118,292.86
December	2262.78	\$128,978.00	16993	\$10,196.00	\$130,123.34

Return

# Fuel Costs

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$$\mathbf{Fuel\ Costs = Fuel\ Requirements \times Fuel\ Rate}$$

Cost per BDT	=	\$53
Cost per therm	=	\$0.60

\*Additional fuel requirements were calculated as the difference between the estimated fuel requirements for the turbine system minus the fuel requirements of the current system.

# Savings

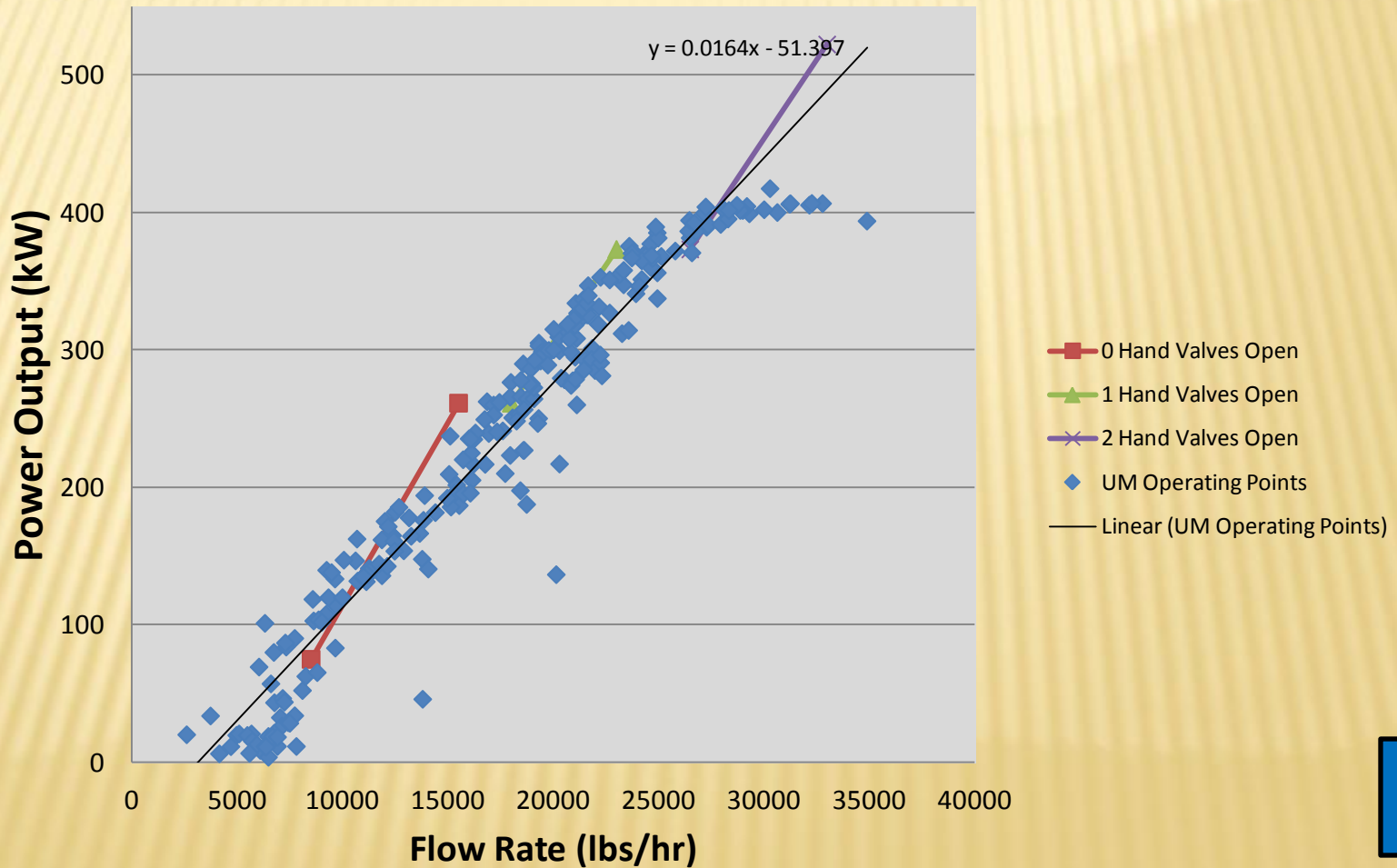
**\$0.0586/kWh**

Turbine Revenue		
	703E	K Frame
January	\$37,273	\$44,574
February	\$26,668	\$32,710
March	\$24,581	\$30,751
April	\$20,007	\$25,491
May	\$13,474	\$17,928
June	\$8,766	\$12,099
July	\$12,995	\$17,352
August	\$14,476	\$19,127
September	\$10,616	\$14,403
October	\$17,925	\$23,179
November	\$25,769	\$32,075
December	\$32,505	\$39,455

Return

# Montana Validation

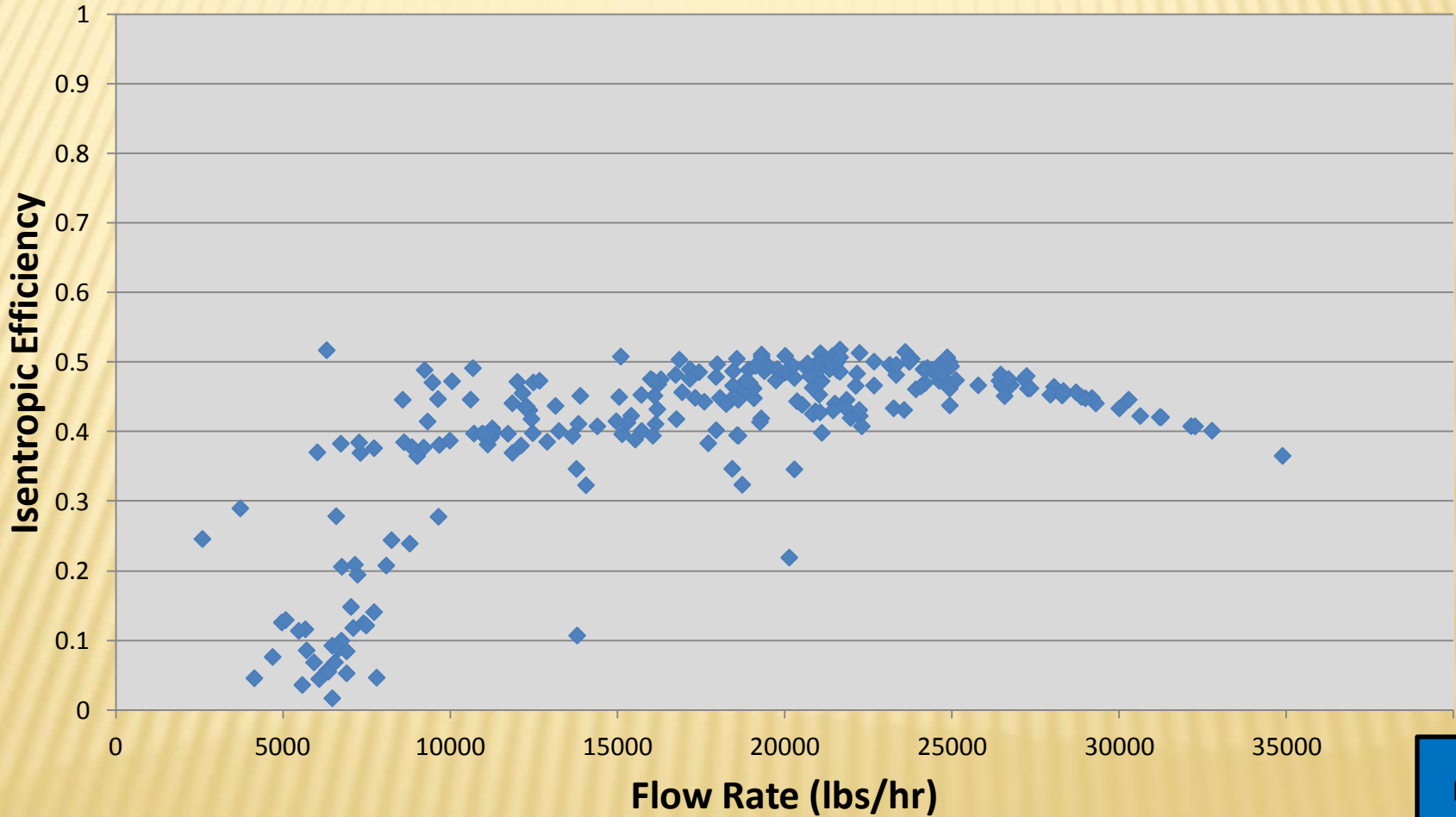
## UM Turbine Power Output vs. Flow Rate (2012)



Return

# Montana Validation

## Isentropic Efficiency vs. Flow Rate (2012)



Return



# Montana Validation

Actual		Theoretical		% Difference
Flow	efficiency	Flow	efficiency	
8500	28.00%	8500	29.19%	4.15%
15500	44.00%	15500	56.02%	24.04%
18000	46.00%	18000	48.24%	4.76%
23000	47.00%	23000	53.93%	13.74%
26500	47.00%	26500	46.81%	0.40%
33000	41.00%	33000	52.63%	24.84%

**Average Difference: 12%**

Return