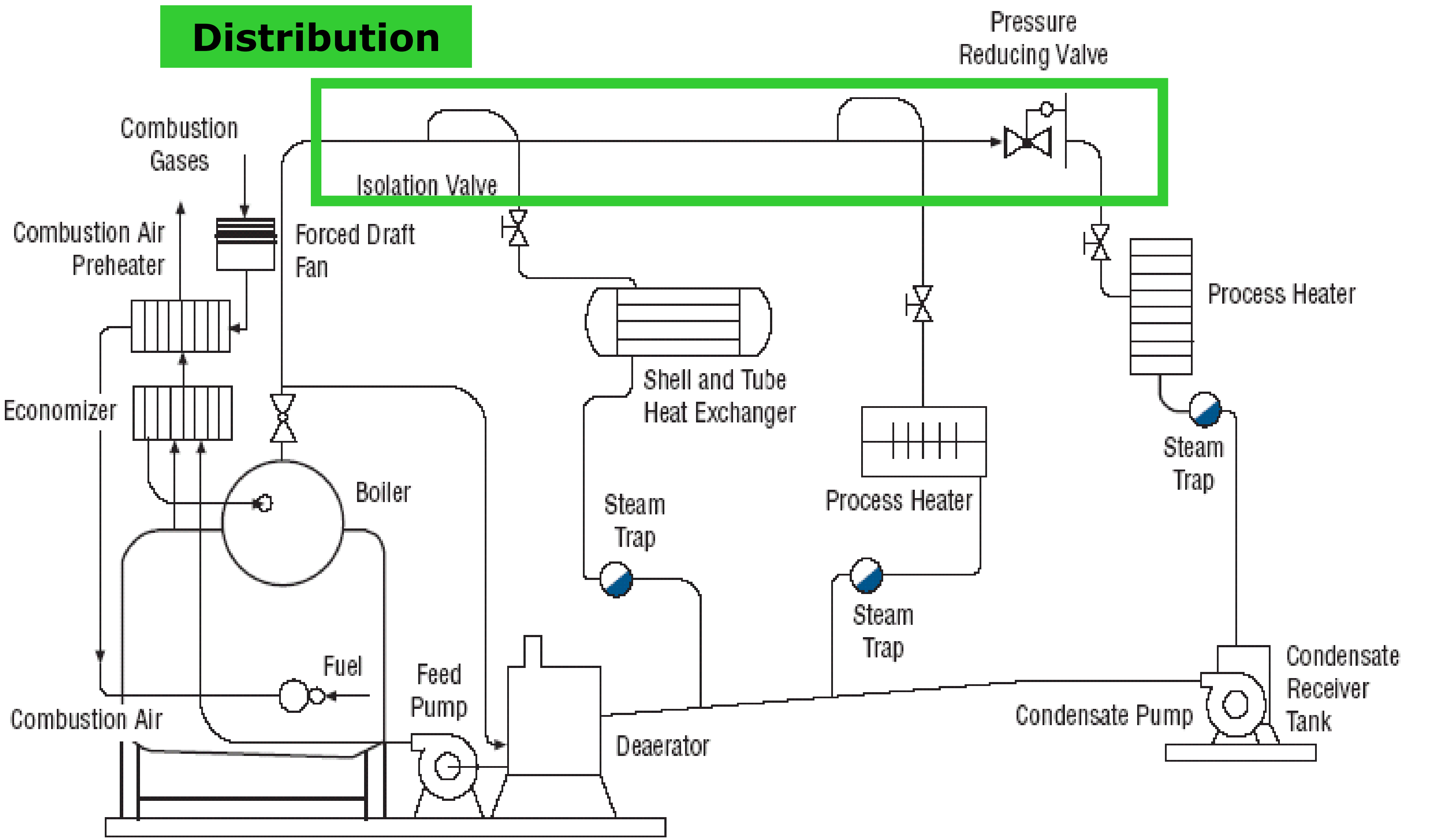
Section 7

Steam System Optimization - Distribution

Steam Leaks

Heat Transfer Loss Through Insulation

Generic Steam System



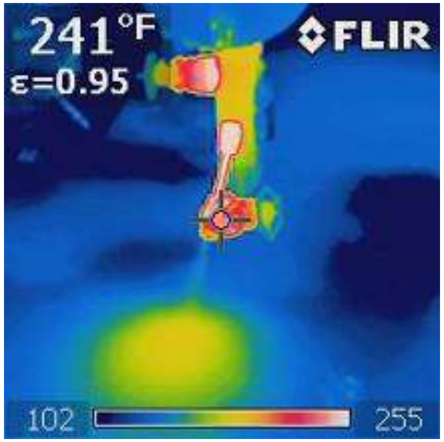
Source: US DOE ITP Steam BestPractices Program

Steam Leaks

- ✓ End-user quote – *"Steam leaks are an essential component of my system, if I don't hear or see them, I can't tell if my steam system is operating!"*

Steam Leaks

- ✓ Steam leaks occur everywhere but most common are places such as:
  - Flanges and gasketed joints
  - Pipe fittings
  - Valves, Stems and packings
  - Steam traps
  - Relief valves
  - Pipe failures, etc.



- ✓ An "order of magnitude" steam loss estimate can provide enough information to determine if the repair must be made immediately, during a future shutdown, or online
- ✓ Pipe failures (steam leaks) often present a "safety issue" that demands immediate attention

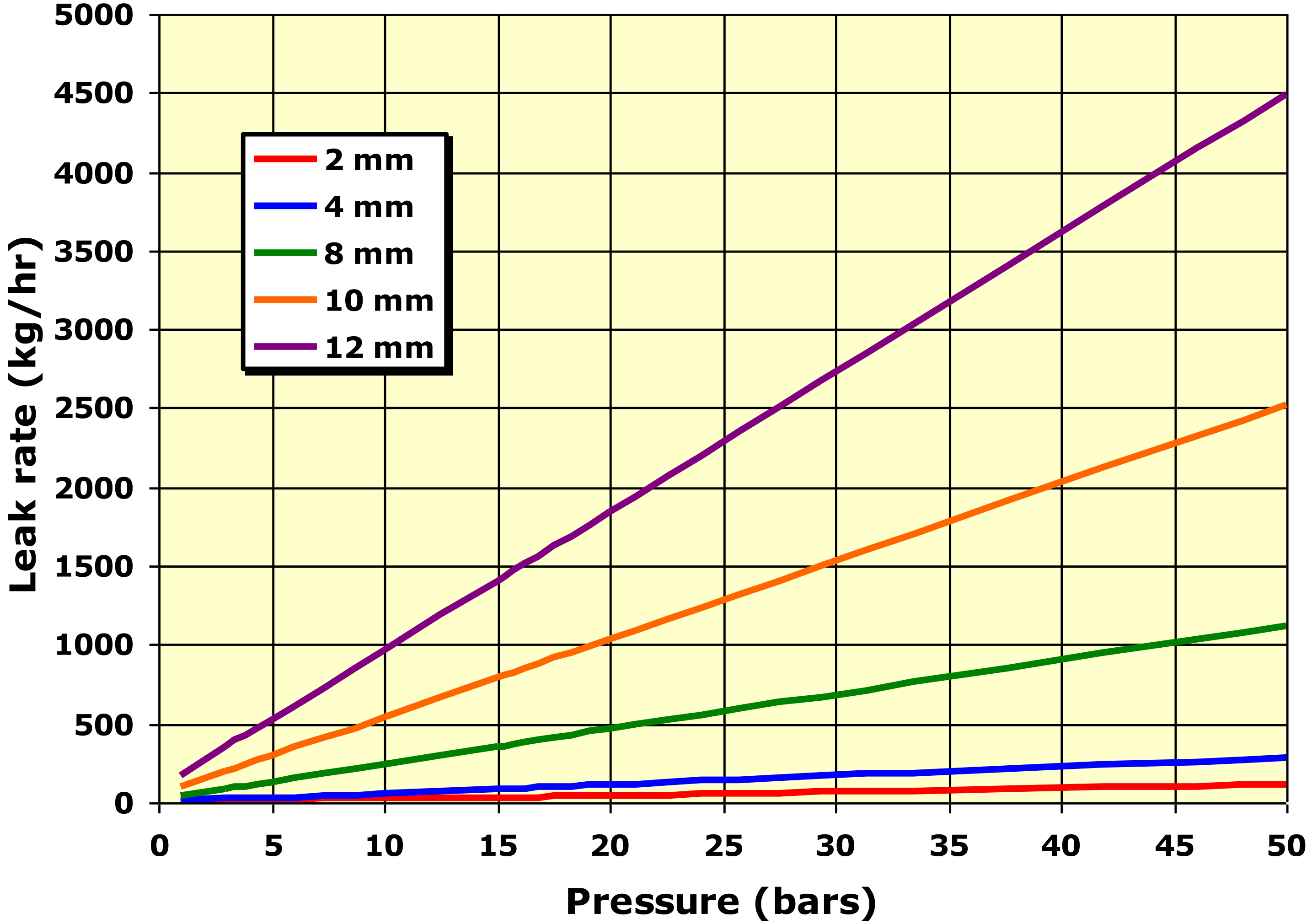
Steam Leaks

✓ Methods to determine economic impact of steam leaks

- Using SSAT based model
- Empirical and observation based – plume height
- Measurement and calculation based via choked flow equation – Napier's equation
- Field measurement with a pitot tube
- Ultrasonic technique, specific manufacturers' instrument and protocol (standard) based
- Other system or equipment balance methodologies

✓ Condensate leakage can be measured by stop watch and bucket methodology

Steam Leaks


5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Leak rate (kg/hr)
2 mm
4 mm
8 mm
10 mm
12 mm
0
5
10
15
20
25
30
35
40
45
50
Pressure (bars)

Steam Leaks

- Napier's choked flow equation

$$m_{steam} = 0.695 \times A_{orifice} \times P_{steam}$$

- This equation is valid for
  - Choked flow conditions: Exhaust pressure < $0.51 * P_{steam}$
  - Coefficient of discharge = 0.695
  - $A_{orifice}$ is area of orifice (or leakage) in mm^2
  - P_{steam} is the steam pressure in bars (absolute)

- Steam Leakage cost can be determined by multiplying the leakage rate with unit steam cost

Example Steam System

- ✓ Steam leak of ~4 mm diameter orifice was found on the 2 barg header. Estimate the steam leak cost.
- ✓ Napier's choked flow equation

$$m_{steam} = 0.695 \times A_{orifice} \times P_{steam}$$

$$m_{steam} = 0.695 \times 12.56 \times 3 = 26.2\ kg/hr$$

- ✓ Unit Steam Cost: $91.67 per 1,000 kg

$$Leak\ Cost = m_{steam} \times \kappa_{steam}$$

$$Leak\ Cost = \frac{26.2 \times 47.34 \times 8{,}760}{1{,}000} \approx \$10{,}900/yr$$

SSAT Project 17 Steam Leaks

- ✓ Number of steam leaks estimated by SSAT model
  - Assumes a steam leak maintenance program was completed 6 months ago
  - Number of steam leaks are equal to 1% of the number of traps specified in the "Quick Start" section
  - Very gross savings estimate
- ✓ New number of steam leaks input by User
  - Gross savings estimate
- ✓ It is advised to use these methods for <u>gross estimates ONLY</u>

SSAT Project 1 for Steam Leaks

- ✓ Steam leak of ~4 mm diameter orifice was found on the 2 barg header. Estimate the steam leak cost.
- ✓ Napier's choked flow equation

$$m_{steam} = 0.695 \times A_{orifice} \times P_{steam}$$

$$m_{steam} = 0.695 \times 12.56 \times 3 = 26.2\, kg/hr$$

- ✓ Complete Project 1 – Steam Demand Savings on the respective header where the leaks were eliminated

SSAT Project 1 for Steam Leaks

Project 1 - Steam Demand Savings (Changing the process steam requirements)
Current use - HP: 20 t/h (12273 kW) MP: 40 t/h (26660 kW) LP: 76 t/h (54448 kW)

Do you wish to specify steam demand savings?	Yes

If yes, enter HP steam saving	0 t/h	
If yes, enter MP steam saving	0 t/h	
If yes, enter LP steam saving	0.0262 t/h	

Note: A negative saving can be entered to model an increase in steam demand

Note: The savings have been converted to heat duties of 0 kW (HP), 0 kW (MP) and 19 kW (LP) based on current header enthalpies

Note: These heat duties are then used to determine the actual flow change in the Projects Model based on the calculated header enthalpies

Results Summary

SSAT Default 3 Header Metric Model Moldova Ex 5

Model Status : OK

Cost Summary ($ '000s/yr)	Current Operation	After Projects	Reduction	
Power Cost	6,132	6,132	0	0.0%
Fuel Cost	57,726	57,715	10	0.0%
Make-Up Water Cost	1,136	1,135	0	0.0%
Total Cost (in $ '000s/yr)	**64,993**	**64,982**	**11**	**0.0%**

Key Points / Action Items

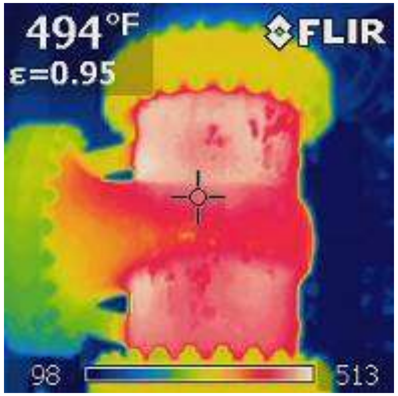
1. Steam leaks occur in all plants and a continuous improvement type steam leak management program should be implemented in industrial plants

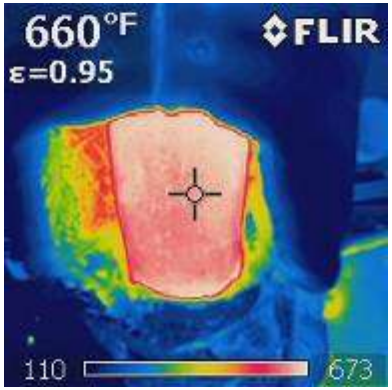
2. An "order of magnitude" steam loss estimate can provide enough information to determine if the repair must be made immediately, during a future shutdown, or online

Steam System Insulation

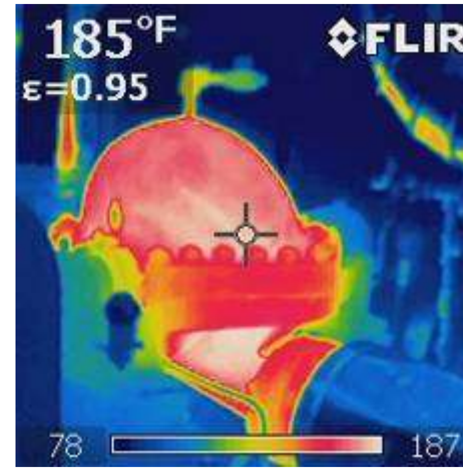
✓ Why is insulation necessary on steam systems?
- Personnel safety – high temperatures
- Minimize energy losses
- Protection from ambient conditions
- Preserve system integrity

✓ Typical areas of insulation improvement opportunities
- Distribution headers
- Inspection man-ways
- Valves
- Condensate return lines
- End-use equipment
- Storage tanks, vessels, etc.





Steam System Insulation



- ✓ There are several reasons for damaged or missing insulation and hence, energy savings opportunities in the insulation area
  - Missing insulation due to maintenance activities
  - Missing / damaged insulation due to abuse
  - Damaged insulation due to accidents
  - Normal wear and tear of insulation due to ambient conditions
  - Valves and other components not insulated

Steam System Insulation

✓ Some basic instruments, software and basic data required to quantify the economic impact of insulation

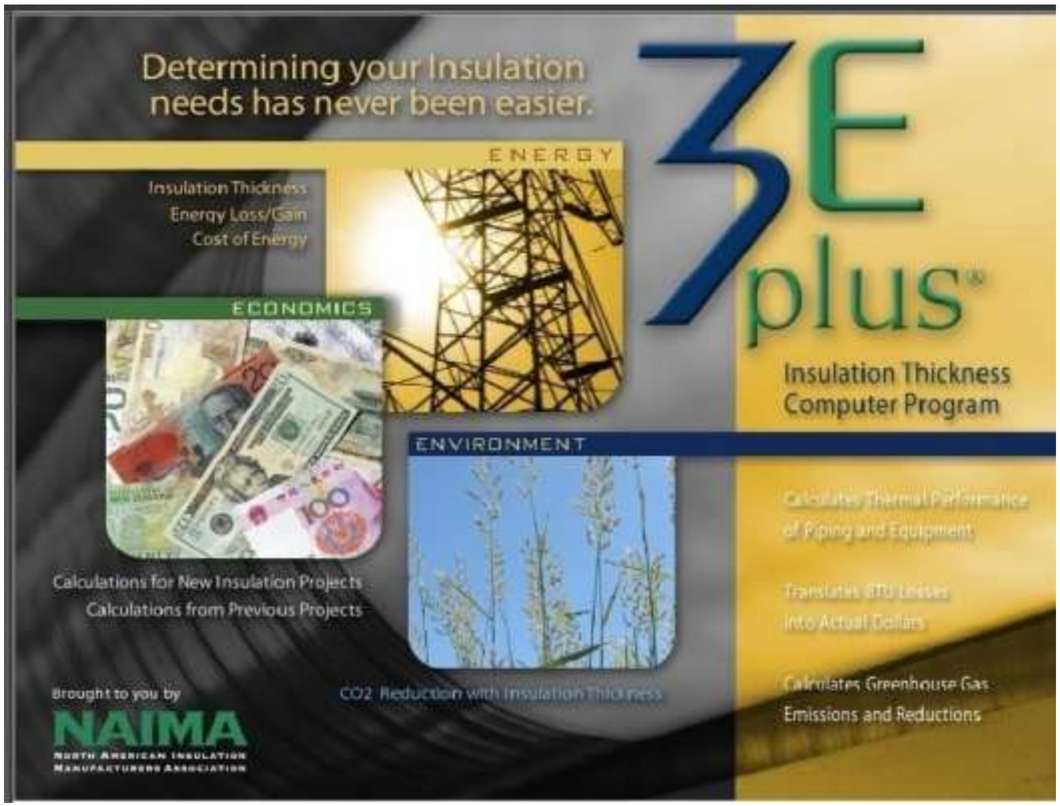
- Infra-red thermography camera
- Infra-red temperature gun
- Measuring tape
- 3E Plus insulation evaluation software
- Operating information
  - Hours per year
- Ambient conditions
  - Temperature
  - Wind

Insulation Tool – 3EPlus

- ✓ North American Insulation Manufacturers Association (NAIMA) developed 3EPlus - determines optimum insulation thickness for a wide variety of insulating materials

- ✓ Software outputs include:
  - Surface heat transfer loss
  - Insulation surface temperature
  - Simple payback of an insulating project

Insulation Evaluation Software



http://www.pipeinsulation.org/

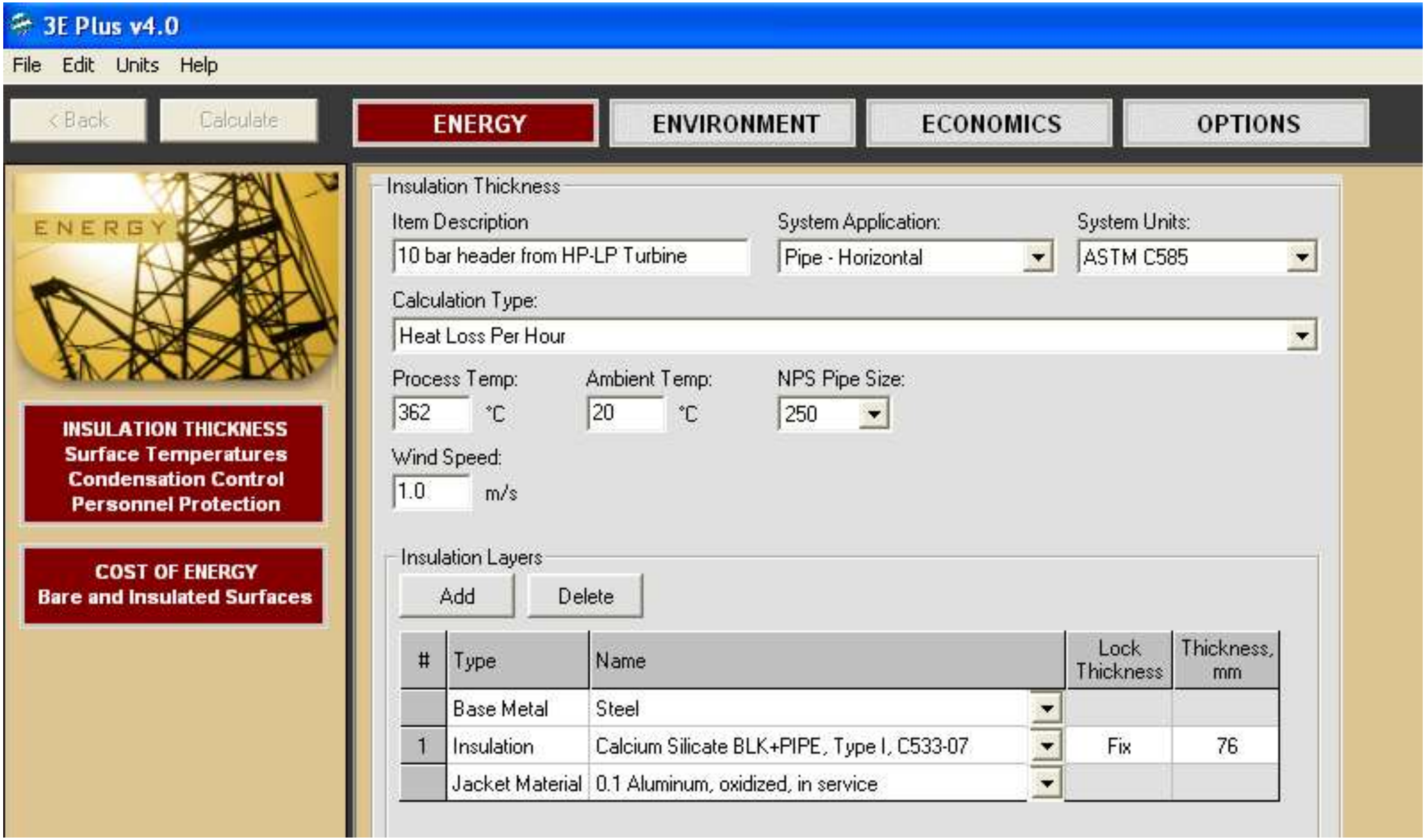
- ✓ Free Program available from NAIMA
- ✓ **E**nergy
  - Heat Loss
  - Cost Impact
- ✓ **E**nvironment
- ✓ **E**conomic Insulation Thickness
  - Life Cycle Cost Analysis

Example Steam System - Missing Insulation

- ✓ A 10 m long section of 10 bar steam header is observed to be un-insulated
  - 25.4 cm nominal diameter
  - Steam temperature is ~362°C
- ✓ Estimate the economic insulation impact.

Source: US DOE ITP Steam BestPractices Program

Insulation Evaluation



Insulation Evaluation

3E Plus v4.0

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INSULATION THICKNESS
Surface Temperatures
Condensation Control
Personnel Protection

COST OF ENERGY
Bare and Insulated Surfaces

Heat Loss Per Hour Report

Item Description: **10 bar header from HP-LP Turbine** System Units: **ASTM C585**
Geometry Description: **Steel Pipe - Horizontal**
Bare Surface Emittance: **0.8** Nominal Pipe Size: **250 mm**
Process Temp: **362.0 °C** Ave. Ambient Temp: **20.0 °C** Ave. Wind Speed: **1.0 m/s**
Relative Humidity: **N/A** Dew Point: **N/A**
Condensation Control Thickness: **N/A**
Outer Jacket Material: **Aluminum, oxidized, in service** Outer Surface Emittance: **0.1**
Insulation Layer 1: **Calcium Silicate BLK+PIPE, Type I,** Thickness: **76.0 mm**

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Variable Insulation Thickness	Surface Temp (°C)	Heat Loss (W/m)	Efficiency (%)
Bare	360.0	8449.00	
Layer 1	57.2	347.70	95.89

Insulation Evaluation

$$Q_{saved} = (8{,}449 - 347.7) \times 10 = 81.0\, kW$$

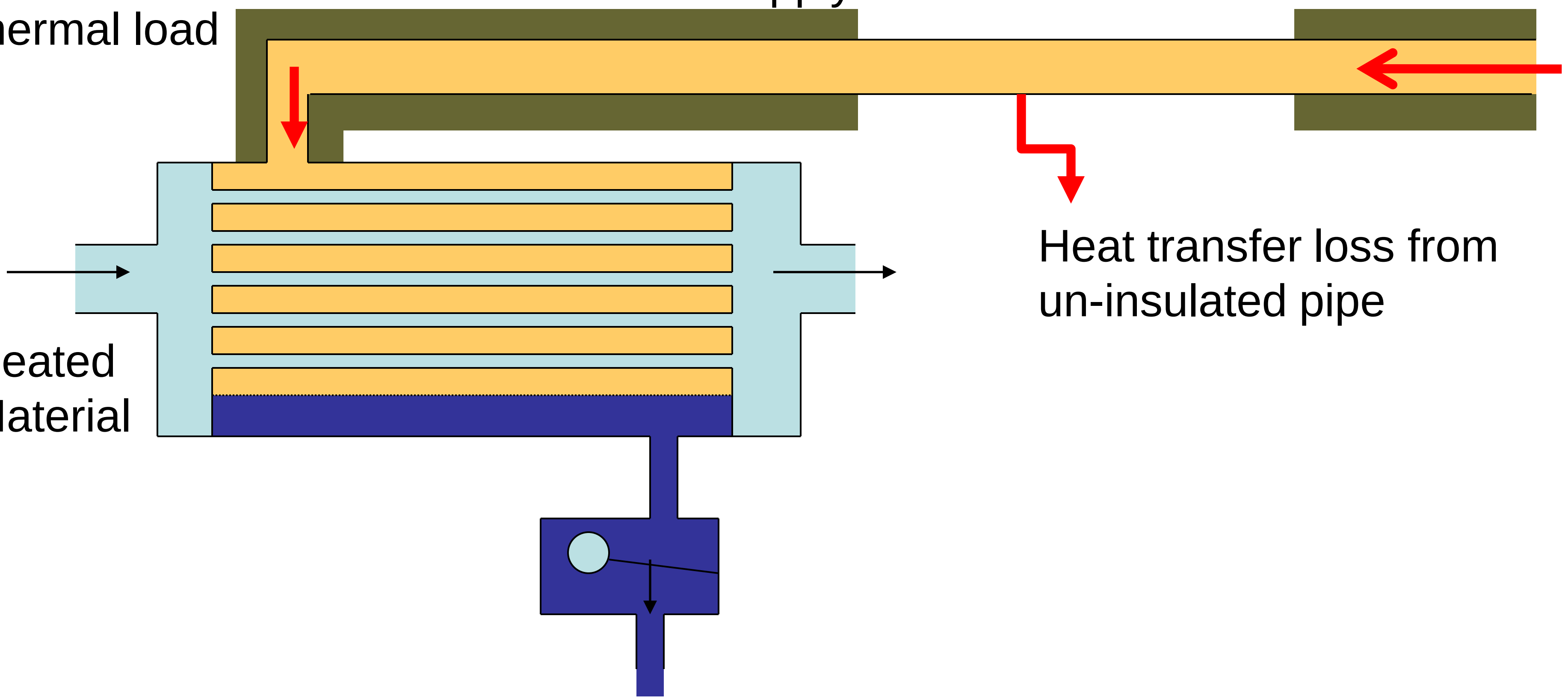
$$Fuelsaved = 81.0 \frac{kJ}{s} \times 3{,}600 \frac{s}{hr} \times 8{,}760 \frac{hr}{yr} \times \frac{1}{0.817} = 3{,}127 \frac{GJ}{yr}$$

$$Fuelsaved = 3{,}127 \frac{GJ}{yr} \times \frac{1}{40{,}144} \frac{Nm^3}{kJ} \times 1{,}000 \times 1{,}000 = 77{,}895 \frac{Nm^3}{yr}$$

$$Savings = 77{,}895 \frac{Nm^3}{yr} \times 0.52 \frac{\$}{Nm^3} = 40{,}500 \frac{\$}{yr}$$

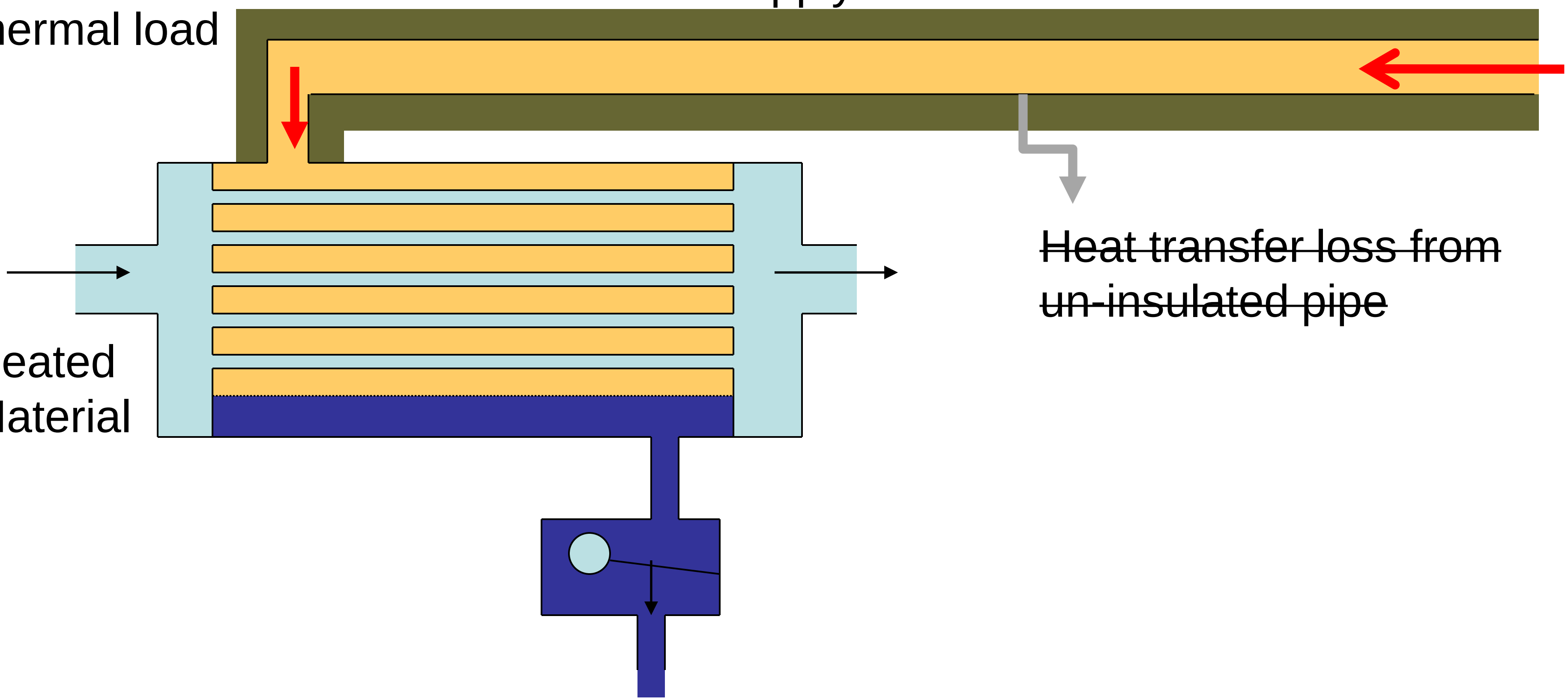
Equivalent Steam Demand

The total thermal energy supply includes the heat exchanger load and the un-insulated pipe load



Equivalent Steam Demand

The total thermal load will decrease if the pipe is insulated—this will decrease the heat exchanger steam demand



Energy Loss Converted to Steam Loss

✓ If the energy impact is realized “at steam cost”:

$$\dot{Q}_{total} = \dot{q}_{per\,length} L_{total}$$

$$\dot{Q}_{total} = \left(8{,}449\,\tfrac{W}{m} - 347.7\,\tfrac{W}{m}\right)\left(10\ m\right)$$

$$\dot{Q}_{total} = 81.0\ kW$$

Marginal Steam Costs	
(based on current operation)	
HP ($/t)	47.34
MP ($/t)	47.34
LP ($/t)	46.64

Energy Loss Converted to Steam Loss

Location	Temperature [°C]	Specific Volume [m³/kg]	Enthalpy [kJ/kg]	Quality [%]	Pressure [bar(g)]
Steam	362	0.26130	3,181.0	****	10.00
Saturated vapor	184	0.17730	2,781.0	100.0	10.00
Saturated liquid	184	0.00113	781.5	0.0	10.00

$$\dot{m}_{steam} = \frac{\dot{Q}_{total}}{\left(h_{steam} - h_{condensate}\right)} = \frac{81.0\,kW}{\left(3{,}181\,\frac{kJ}{kg} - 781.5\,\frac{kJ}{kg}\right)}$$

$$\dot{m}_{steam} = 0.033\,\frac{kg}{s} = 121.5\,\frac{kg}{hr}$$

Energy Loss Converted to Steam Loss

$$\dot{K}_{steam} = \dot{m}_{steam} k_{steam}$$

If the cost of steam is known

$$\dot{K}_{steam} = 121.5 \frac{kg}{hr} \left(47.34 \frac{\$}{tonne} \right) \left(\frac{1}{1{,}000} \frac{tonne}{kg} \right)$$

$$\dot{K}_{steam} = 5.75 \frac{\$}{hr} \left(\frac{8{,}760 hrs}{1 yr} \right) = 50{,}400 \frac{\$}{yr}$$

- SSAT steam demand project can also be utilized

SSAT Project 1 for Insulation

Project 1 - Steam Demand Savings (Changing the process steam requirements)
Current use - HP: 20 t/h (12273 kW) MP: 40 t/h (26660 kW) LP: 76 t/h (54448 kW)

Do you wish to specify steam demand savings?	Yes

If yes, enter HP steam saving	0 t/h
If yes, enter MP steam saving	0.1215 t/h
If yes, enter LP steam saving	0 t/h

Note: A negative saving can be entered to model an increase in steam demand

Note: The savings have been converted to heat duties of 0 kW (HP), 81 kW (MP) and 0 kW (LP) based on current header enthalpies

Note: These heat duties are then used to determine the actual flow change in the Projects Model based on the calculated header enthalpies

Results Summary

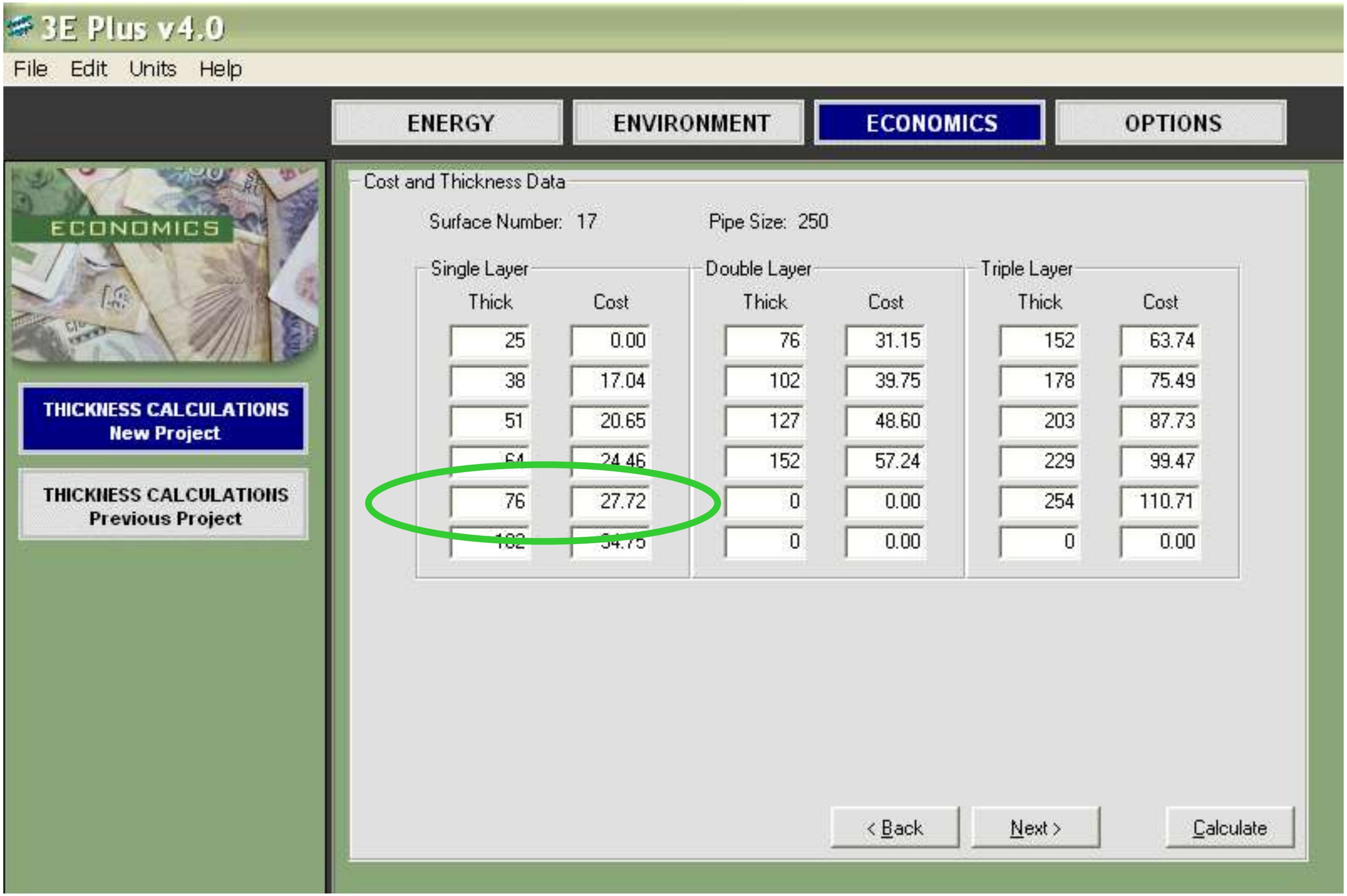
SSAT Default 3 Header Metric Model Moldova Ex 5

Model Status : OK

Cost Summary ($ '000s/yr)	Current Operation	After Projects	Reduction	
Power Cost	6,132	6,132	0	0.0%
Fuel Cost	57,726	57,676	49	0.1%
Make-Up Water Cost	1,136	1,134	1	0.1%
Total Cost (in $ '000s/yr)	**64,993**	**64,943**	**50**	**0.1%**

On-Site Emissions	Current Operation	After Projects	Reduction	
CO_2 Emissions	231510 t/yr	231312 t/yr	198 t/yr	0.1%
SO_x Emissions	0 t/yr	0 t/yr	0 t/yr	N/A
NO_x Emissions	458 t/yr	458 t/yr	0 t/yr	0.1%

Insulation Evaluation



Insulation Evaluation

3E Plus v4.0

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CO2, NOX & CE REDUCTION
Emission Reduction Table

Pollutant Reduction

Item Description: **10 bar header from HP-LP Turbine** System Units: **ASTM C585**
Geometry Description: **Steel Pipe - Horizontal**
Bare Surface Emittance: **0.8** Nominal Pipe Size: **250 mm**
Process Temp: **362.0 °C** Ave. Ambient Temp: **20.0 °C** Ave. Wind Speed: **1.0 m/s**
Fuel: **Natural Gas** Heat Content: **4.0144E+07J/m^3**
Fuel Cost: **1 $/m^3** Efficiency: **80%** Hours/Year: **8760**
Outer Jacket Material: **Aluminum, oxidized, in service** Outer Surface Emittance: **0.1**
Insulation Layer 1: **Calcium Silicate BLK+PIPE, Type I,** Thickness: **76.0 mm**

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Variable Insulation Thickness	CO2 (kg/m/yr)	NOx (kg/m/yr)	CE (kg/m/yr)
Bare	16690.000	33.470	4547.000
Layer 1	686.618	1.377	187.089

Common Insulation Issues

- ✓ Missing insulation due to maintenance activities
- ✓ Missing insulation due to abuse
- ✓ Damaged insulation
- ✓ Valves and other components not insulated

Insulation Evaluation for Non-Cogeneration Systems

- ✓ Steam systems providing thermal energy only (non-cogeneration) the cost of steam is essentially the cost of fuel divided by boiler efficiency
- ✓ 3E-Plus can be used directly to calculate insulation savings for non-cogeneration systems

SSAT Project 18 - Insulation Loss

Project 18 - Improved Insulation Currently modeled based on percentage heat loss on each header

Do you wish to model the impact of improved insulation?	No

Note: Model will assume that heat losses are reduced to 10% of the current value by improving insulation

<u>Please DO NOT use this Project</u>

SSAT Project 18 - Insulation Loss

- ✓ SSAT insulation calculation provides only a gross estimate for the impact of steam system insulation improvement
- ✓ It is based on reducing heat transfer loss by 90% compared to current “base” case scenario
- ✓ 3EPlus provides a very accurate methodology and should be used in conjunction with SSAT Project 1 – Steam Demand savings to determine the true impact of insulation improvement

Key Points / Action Items

1. *There are several reasons for damaged or missing insulation*
2. *These areas result in significant energy losses and a continuous improvement type insulation appraisal (audit) program should be implemented in industrial plants*
3. *Some basic instruments, heat transfer models and process data are required to quantify the economic impact of missing or damaged insulation*

Common BestPractices - Distribution

- ✓ Repair steam leaks
- ✓ Minimize vented steam
- ✓ Ensure that steam system piping, valves, fittings and vessels are well insulated
- ✓ Isolate steam from unused lines
- ✓ Minimize flows through pressure reducing stations
- ✓ Reduce pressure drop in headers
- ✓ Drain condensate from steam headers

Source: US DOE BestPractices Steam System Sourcebook