OUTLINE

- Who is REHAU
- What is PEXa
  - History
  - Applications
  - Capabilities
- Why use PEXa for geothermal
  - PEXa capabilities
- Borehole response testing
- PEXa system and design considerations
  - Dimensional data
  - Rules of thumb
- Components of PEXa ground loop
- Reference projects
ABOUT REHAU

THE REHAU GROUP:
POLYMER MANUFACTURER, PEX PIONEER

- Founded over 60 years ago in 1948 in the town of Rehau, Germany
- Independent, privately held company
  - Still family-owned
  - Started as “REHAU”, still “REHAU”
- Approximately 15,000 employees at more than 170 locations around the world
- Pioneer of PEX piping systems starting in 1968
- More than one billion feet of PEX pipes installed worldwide
  - Five PEX plants globally, including NA’s plant in Alabama

REHAU NA Headquarters, Leesburg, VA
ALL AROUND THE WORLD
EFFECTIVE WORLDWIDE NETWORK

The worldwide network of REHAU locations together with suppliers, customers, research institutes and universities provides optimum results.

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THE REHAU GROUP
“UNLIMITED POLYMER SOLUTIONS”

The performance capability of REHAU is unmatched with regard to its breadth and quality. Many of our polymer-based products and services in the areas of construction, automotive and industry are today’s world leaders.

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PROTECTING THE ENVIRONMENT
THROUGH SUSTAINABLE DESIGN

- Sustainability was defined by the World Commission on Environment and Development in 1987 as “meeting the needs of today without compromising the ability of future generations to meet their own needs.”

- What this means to REHAU:
  - REHAU products provide both economic and environmental benefits
  - REHAU is a responsible manufacturer which considers the long-term when developing products and solutions
  - We see this in PEXa products, providing performance for sustainable design with “green” piping products
WHAT IS PEXa?

CROSS-LINKED POLYETHYLENE

- **PEX** is **Poly Ethylene** that has been chemically or physically modified – cross-linked (X) to cause the molecules to link together, permanently.

- Once PE is cross-linked into PEX, it becomes a thermo-set plastic, meaning that it cannot be melted and reshaped.

- Compared to standard PE pipes, PEX has desirable high temperature strength, reduced sensitivity to notching, improved chemical resistance, and high flexibility.

- There are 3 commercial processes or methods:
  - PEXa: High-pressure peroxide (“Engel”)
  - PEXb: Silane (“moisture cure”)
  - PEXc: Radiation (“electron beam” or “nuclear”)

- PEXa was pioneered by REHAU.
REHAU PEXa
“CROSS-LINKED (X) POLYETHYLENE”

History:
- Dr. Thomas Engel, German Inventor
  - Originally known as “Engel Method”
- REHAU licensed the patent for the special PEXa process in 1967
- Started development work in 1968
- Began series production in 1972 for PEXa radiant heating pipes
- Now known as “High-pressure peroxide” cross-linking, or simply, PEXa

Signatures from original contract

PEXa “molecule”

PEXa STANDARDS AND APPLICATIONS

Construction
Automotive
Industry
REHAU PEXa PIPE
APPLICATIONS

- NA - radiant and hydronic heating, plumbing distribution, fire protection, municipal water supply, process piping and now geothermal piping
- Europe - heating, plumbing, municipal, underground natural gas piping, chilled water, process piping, compressed air, and geothermal applications

WHY USE PEXa PIPES FOR GEOTHERMAL?
RAUGEOTM GROUND LOOP HEAT EXCHANGE SYSTEM

Construction
Automotive
Industry
HOW DOES PEX IMPROVE PROPERTIES FROM HDPE?
THIS PPI DOCUMENT SUMMARIZES THE PROPERTY CHANGE FROM PE TO PEX

- PEX pipe surpasses the performance properties of HDPE pipes
  - Increased environmental stress crack resistance
  - Increased resistance to slow crack growth
  - Increased elongation to break
  - Increased flexibility
  - Increased hydrostatic design basis (HDB) pressure at 180°F (82.2°C)
  - Increased resistance to creep

Source: Reference PPI TN-17

PEXa PIPE CAPABILITIES
CAPABILITIES AND LIMITS
TEMPERATURE / PRESSURE CAPABILITY

- Pipes have long-term pressure ratings* of:
  - 160 psi @ 73.4°F, 130 psi @ 120°F, 100 psi @ 180°F, 80 psi @ 200°F
  - These certifications are based on a 50-year extrapolation according to D 2837
  - Pipes will withstand short-term exposure over 230°F

- Pipes have minimum quick-burst capability (short-term) per ASTM F 876:
  - 475 psi @ 73.4°F, 210 psi @ 180°F, 180 psi @ 200°F
  - REHAU typically achieves a burst strength of 800 psi @ 73.4°F
PEXa PIPE CAPABILITIES
CAPABILITIES AND LIMITS
FLEXIBILITY AND KINK RESISTANCE

Flexibility
- PEXa is more flexible than other piping materials
- Pipes are less likely to kink when bending quickly or too tightly
- Flexible to below -40°F (-40°C); will not become brittle or break at cold temperatures
- Bend radius as tight as 5x the OD is possible without heating
- Bend radius as tight as 3x OD is possible with heating

PEXa U-bend
- Continuous pipe
- No connections in the well
- Factory-made U-bend

Kink Resistance
- PEXa resists kinking, even well below freezing temperatures
- If kinked, PEXa can be field-repaired without cutting
  - See instructions
  - Be sure to let pipe cool before moving it or applying any stress

If REHAU PEXa pipe becomes kinked… …it may be heated to 265°F (130°C) with hot air to remove the kink.

Non-Barrier pipe turns clear when fully heated; coated pipes simply re-round

Stop when the kink is gone!
Do not overheat the pipe!
PEXa PIPE CAPABILITIES
CAPABILITIES AND LIMITS
ENVIRONMENTAL RESISTANCE

Freeze resistance
- With room to expand evenly along its length, PEXa pipe will expand when frozen and not break; pipe will return when thawed
- This helps a pipe installed in a wall, but not when inside a floor
- Pipes inside a concrete floor are likely to break if allowed to freeze

UV Resistance (see REHAU TB218)
- RAUPEX O2 Barrier – 30 days
- RAUPEX UV Shield White – up to 3 months
- RAUPEX UV Shield Red & Blue – up to 1 year
- RAUGEO Collect – up to 3 months

PEXa PIPE CAPABILITIES
CAPABILITIES AND LIMITS
ENVIRONMENTAL RESISTANCE

Chemical resistance (see REHAU TB120R2)
- REHAU PEXa pipes are resistant to glycols, latex paints, silicone, urethane foam, most acids and bases
- REHAU PEXa Non-Barrier pipes may be sensitive to certain adhesives at elevated temperatures
  - Do not apply adhesive tape to REHAU PEXa Non-Barrier pipes
  - If in doubt, check with REHAU

Chlorine and Chloramines potable water disinfectants (see REHAU TB135R2)
- REHAU PEXa is chlorine resistant
  - PPI category 3006
- Tested with free chlorine (Cl₂) at 4.0 ppm, pH 6.8, 80 psi, 140°F
- Chloramines (another water disinfectant) are not as aggressive as free chlorine
PExa PIPE CAPABILITIES
FLEXIBILITY
RAUGEO PExa AND HDPE TENSILE TEST - ELONGATION COMPARISON

Pipes are stretched in tensile testing machine at 10 inches/minute:
- HDPE tears at only 65% elongation
- RAUGEO PExa stretches more than 336% before breaking

Conclusions:
- PExa has greater flexibility and similar short-term strength

PEXa PIPE CAPABILITIES
ENVIRONMENTAL STRESS CRACK RESISTANCE
RESISTANCE TO IMPACT, SLOW CRACK GROWTH, ROCK IMPINGEMENT, SCRATCHES

Potential sources of notches to pipes
- Handling and transportation
- Installation
  - Borehole edges, trenches
- Post-installation
  - Rock impingement
  - Earth movement

PEXa has high impact resistance
- More flexible than other piping materials
- Will not crush, kink or collapse when proper backfill techniques are used
- Superior notch resistance
- Will not dent or crush from typical impacts
Leesburg, VA:
- Four six-inch diameter borings were drilled to a depth of three hundred feet
  - 1" DRISCOLEX™ 5300 Climate Guard® HDPE single u-bend
  - 1" RAUGE single u-bend
  - 1" RAUGE double u-bend without spacers
  - 1" RAUGE double u-bend with spacers
  - Completed with 1" U-bends and thermal grout with a conductivity of 1.0 BTU/hr-°F-ft
REHAU IN-SITU BOREHOLE THERMAL PERFORMANCE TESTING
BOWMAN GEOTHERMAL ANALYSIS

- Results of 48 hr TC tests per ASHRAE procedures

<table>
<thead>
<tr>
<th>Well No.</th>
<th>Configuration</th>
<th>FTC (BTU/hr°F·ft)</th>
<th>Diffusivity (ft²/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well 1</td>
<td>Double PEXa with no spacers</td>
<td>1.73</td>
<td>1.32</td>
</tr>
<tr>
<td>Well 2</td>
<td>Single HDPE loop</td>
<td>1.78</td>
<td>1.36</td>
</tr>
<tr>
<td>Well 3</td>
<td>Double PEXa with 3&quot; spacers</td>
<td>1.86</td>
<td>1.39</td>
</tr>
<tr>
<td>Well 4</td>
<td>Single PEXa loop</td>
<td>1.72</td>
<td>1.31</td>
</tr>
</tbody>
</table>

- Much lower BTR for the double u-bends
- BTR values have a significant impact on borehole length

<table>
<thead>
<tr>
<th>Well No.</th>
<th>Configuration</th>
<th>Effective BTR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well 1</td>
<td>Double PEXa with no spacers</td>
<td>0.043</td>
</tr>
<tr>
<td>Well 2</td>
<td>Single HDPE loop</td>
<td>0.095</td>
</tr>
<tr>
<td>Well 3</td>
<td>Double PEXa with 3&quot; spacers</td>
<td>0.002</td>
</tr>
<tr>
<td>Well 4</td>
<td>Single PEXa loop</td>
<td>0.148</td>
</tr>
</tbody>
</table>

REHAU IN-SITU BOREHOLE THERMAL PERFORMANCE TESTING
BOWMAN GEOTHERMAL ANALYSIS
SUMMATION

- See the “REHAU in-situ Borehole Thermal Performance Testing” report authored by Bowman Geothermal for specifics.

<table>
<thead>
<tr>
<th>Loop Type</th>
<th>Basis</th>
<th>Residence Heating Dominated</th>
<th>Residence Strongly Cooling Dominated</th>
<th>Visitors Center Heating Dominated</th>
<th>Visitors Center Strongly Cooling Dominated</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDR11 HDPE</td>
<td>REHAU Test Results</td>
<td>0.95</td>
<td>150</td>
<td>115</td>
<td>165</td>
</tr>
<tr>
<td>Double PEXa SDR9-No Spacers</td>
<td>.043</td>
<td>135 (-10%)</td>
<td>100 (-13%)</td>
<td>140 (-15%)</td>
<td>110 (-18%)</td>
</tr>
<tr>
<td>Double PEXa SDR9-Spacers</td>
<td>.001</td>
<td>120 (-20%)</td>
<td>85 (-24%)</td>
<td>125 (-24%)</td>
<td>95 (-30%)</td>
</tr>
<tr>
<td>SDR11 HDPE Computed Grout TC=1.0</td>
<td>0.24</td>
<td>205</td>
<td>170</td>
<td>235</td>
<td>205</td>
</tr>
<tr>
<td>Double PEXa SDR9-Spacers</td>
<td>0.11</td>
<td>155 (-24%)</td>
<td>125 (-26%)</td>
<td>175 (-26%)</td>
<td>140 (-32%)</td>
</tr>
<tr>
<td>SDR11 HDPE Computed Grout TC=0.4</td>
<td>0.46</td>
<td>280</td>
<td>245</td>
<td>335</td>
<td>305</td>
</tr>
<tr>
<td>Double PEXa SDR9-Spacers</td>
<td>0.19</td>
<td>185 (-34%)</td>
<td>150 (-39%)</td>
<td>210 (-33%)</td>
<td>180 (-41%)</td>
</tr>
</tbody>
</table>
# PEXa AND HDPE

## DIMENSIONAL DIFFERENCES

<table>
<thead>
<tr>
<th>Pipe Material</th>
<th>3/4&quot; HDPE IPS SDR 11</th>
<th>1&quot; PEXa CTS SDR 9</th>
<th>1&quot; HDPE IPS SDR 11</th>
</tr>
</thead>
<tbody>
<tr>
<td>OD</td>
<td>1.050 in.</td>
<td>1.125 in.</td>
<td>1.315 in.</td>
</tr>
<tr>
<td>ID</td>
<td>0.860 in.</td>
<td>0.875 in.</td>
<td>1.077 in.</td>
</tr>
<tr>
<td>Wall Thickness</td>
<td>0.095 in.</td>
<td>0.125 in.</td>
<td>0.120 in.</td>
</tr>
<tr>
<td>Thermal Conductivity</td>
<td>0.24 BTU/hr-ft-F</td>
<td>0.24 BTU/hr-ft-F</td>
<td>0.24 BTU/hr-ft-F</td>
</tr>
<tr>
<td>Pipe Roughness</td>
<td>0.00157&quot;</td>
<td>0.00028&quot;</td>
<td>0.00157&quot;</td>
</tr>
<tr>
<td>Pressure Rating</td>
<td>160 psi @ 73.4°F</td>
<td>160 psi @ 73.4°F</td>
<td>160 psi @ 73.4°F</td>
</tr>
<tr>
<td>Head Loss (5 gpm, water)</td>
<td>4.47 ft/100ft</td>
<td>4.12 ft/100ft</td>
<td>1.53 ft/100ft</td>
</tr>
</tbody>
</table>
PEXa AND HDPE
PRESSURE LOSS OF GROUND HEAT EXCHANGERS
WITH PROPYLENE GLYCOL 20%

Horizontal loop
- 250 - 350 ft. of trench (500 - 700 ft. of pipe) per ton of energy required

Vertical borehole
- Maximum borehole depth 300 ft
- For a single u-bend, 300 ft = 1.3 tons = 15,600 BTU/hr
- For a double u-bend 300 ft = 1.8 tons = 21,600 BTU/hr

U-bend tip dimensions
- 4 inch outside diameter
- 5 inch borehole is required

PEXa RULES OF THUMB
HORIZONTAL LOOPS AND VERTICAL BOREHOLES

RAUGEIO Single U-bend

RAUGEIO Double U-bend
RAUGEOM™ GROUND LOOP HEAT EXCHANGER
COMPONENTS OF A PEXa GROUND LOOP

RAUGEOM GROUND LOOP HEAT EXCHANGE SYSTEM
BASIC SYSTEM COMPONENTS

1 Horizontal ground loop
2 Vertical u-bend
3 Geothermal manifold
BASIC SYSTEM COMPONENTS

ADDITIONAL FITTING OPTION
ASTM F1055: POLYETHYLENE ELECTRO FUSION FITTINGS

- Standard HDPE electro fusion fittings are compatible with RAUGE pipes
- PEXa pipe is the only type of PEX that provides an effective electro fusion joint
  - Used in Europe in gas and geothermal installations for the last 10 years
- Follow the same assembly procedures used for HDPE pipe and F1055 EF fittings
- Manufacturer must provide instructions and tool recommendations

ADDITIONAL FITTING OPTION

ASTM F1055: POLYETHYLENE ELECTRO FUSION FITTINGS

- Electro Fusion Coupling on PEXa pipe

RAUGE PEXa GEOTHERMAL SYSTEM

“ENGINEERED” PEXa GEOTHERMAL SOLUTION

SYSTEM BENEFITS

<table>
<thead>
<tr>
<th>System Component</th>
<th>PEXa System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polypropylene Manifold</td>
<td>- Easy-to-balance circuits</td>
</tr>
<tr>
<td></td>
<td>- Easy-to-isolate circuits</td>
</tr>
<tr>
<td></td>
<td>- Easy to purge circuits</td>
</tr>
<tr>
<td></td>
<td>- Factory made</td>
</tr>
<tr>
<td></td>
<td>- Above ground – easily accessed</td>
</tr>
<tr>
<td>PEXa Pipe</td>
<td>- Over 10,000 hr slow crack growth resistance</td>
</tr>
<tr>
<td></td>
<td>- Continuous pipe – no joints</td>
</tr>
<tr>
<td></td>
<td>- 5x OD bending radius</td>
</tr>
<tr>
<td></td>
<td>- Kink recovery</td>
</tr>
<tr>
<td></td>
<td>- Native backfill can be used</td>
</tr>
<tr>
<td></td>
<td>- Temperature operation up to 200°F</td>
</tr>
<tr>
<td>System Configuration</td>
<td>- No fusion – lower installation skill level; fusion equipment cost not</td>
</tr>
<tr>
<td></td>
<td>required</td>
</tr>
<tr>
<td></td>
<td>- More than 15% more energy extracted when using Double U-Bend</td>
</tr>
<tr>
<td></td>
<td>- Lower drilling costs/shorter wells – Double U-Bend</td>
</tr>
</tbody>
</table>

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RAUGEO GROUND LOOP HEAT EXCHANGE SYSTEM
REFERENCE PROJECTS

VIRGINIA RESIDENCE
WINCHESTER READINESS CENTER
COMMONWEALTH OF VIRGINIA DEPT. OF MILITARY AFFAIRS

Project
- Winchester Readiness Center, Commonwealth of Virginia Department of Military Affairs

System Used
- PEXa Ground Loop Heat Exchanger

Description
- 25 wells each approximately 300 ft deep
- Approximately 2 tons per 300 ft well; 52.5 ton cooling load
- 100% “Home-Run” from GSHP direct to the vault
- 100% PEXa continuous Double U-bend loop technique
- No buried joints in the wells or in trenches
- Very reliable and fast connections
- Easy to balance and purge each circuit
- 100% access and control to any individual circuit
MINNIE HOWARD NINTH GRADE CENTER
FOR THE ALEXANDRIA CITY PUBLIC SCHOOLS
ALEXANDRIA, VIRGINIA

Project
- Minnie Howard Ninth Grade Center, Alexandria, VA

System Used
- PEXa Ground Loop Heat Exchanger

Description
- 42 solar collector panels – 1,700 sq.ft. of collector area
- 62 wells - 300 ft deep PEXa double u-bend direct
- Polymer manifolds in buried, accessible vaults – 100% access
- Easy to balance and purge each circuit

Calculated Payback
- ~8 years (LIFETIME from WELL FIELD is 50+ years)
- Life cycle cost savings $430,000 over 20 years (in PV 2008 Dollars)
- Reduction of greenhouse gases 50,000 kg CO2 per year

MINNIE HOWARD ELEMENTARY SCHOOL
DIFFERENT CIRCUIT LENGTHS
DRAKE LANDING SOLAR COMMUNITY
OKOTOKS, ALBERTA

Project:
- Ground-source energy storage; temps up to 90°C (200°F)
- Drake Landing Solar Community, Okotoks/Canada

Systems used:
- 144 PEXa Double U-bend probes

Description:
- Residential area consisting of 52 detached houses, which can use solar energy throughout the entire year by a combination of 800 solar panels with a short-term and long-term heat reservoir, consisting of 144 PEXa-probes. Using this system, it is possible for 65 - 70% of the energy consumption for the hot water supply to be covered. And even up to 90% of the required energy for the room heating is provided in an environmental-friendly manner.

“DAS BIOHAUS” AT CONCORDIA LANGUAGE VILLAGES
BEMIDJI, MINNESOTA

Project:
- BioHaus Environmental Living Centre at Concordia Language Villages, Bemidji, MN

Systems used:
- PEXa Ground Loop Heat Exchanger
- PEXa Plumbing & Radiant Heating
- PP Thermo Earth-Air Heat Exchanger
- Solar Energy System

Description:
- 1st Passivhaus Certified Building in North America, to include geothermal, PEX Plumbing and radiant heating, earth-air heat exchanger and solar thermal. The Passivhaus demonstrates the benefits of system integration with renewable energy systems. It provides a level of energy efficiency beyond that of the U.S. Green Building Council’s LEED (Leadership in Energy and Environmental Design) standard, using 85 percent less energy than comparable U.S. structures.
THANK YOU FOR YOUR ATTENTION
QUESTIONS?