ENGINEERING

RESEARCH

REVIEW 2015

South Dakota State University

Jerome J. Lohr College of Engineering

SDSU

Dear Colleagues,

The dedication and determination our faculty bring to their diverse research interests have made this year one of growth in the Jerome J. Lohr College of Engineering. From a financial perspective, this has been a year with strongly positive outcomes. External funding this past year for our college exceeded $6 million, while the year before we only reached $3.5 million. This is especially pleasing when one realizes that all of these awards are the result of our faculty going head-to-head with the rest of the country in competitive grant programs. Much of this increase has been due to the efforts of our junior faculty members, so this issue features some of their unique work.

These junior faculty projects span a wide range of disciplines. We have professors working on heat pipes to efficiently cool today's high-power computers, using fluid flow modeling to show new stent designs improve blood flow and developing ways to prevent fertilizers from polluting lakes and streams. One of the more unusual new projects is forensic in nature and applies theories from mathematic modeling and statistics to the use of evidence for court proceedings. This work may pave the way for using evidence such as glass fragments and fingerprints based on probability. It seeks to answer questions such as, what is the likelihood that a piece of glass evidence taken from the suspect's clothing came from the crime scene window versus being deposited there by chance?

While the breadth of expertise noted above continues to be a strength of our college, our most focused efforts this past year, as well as into the near future, will be in the area of precision agriculture. After an intense year of study, we have decided to partner with the College of Agriculture and Biological Sciences to develop not only research, but also teaching and service in this area—which is key to the future of our state as well as to the future of our world. By partnering with key companies that service this market, as well as commodity groups and federal agencies, we hope to provide new knowledge that will not only improve yields and profits, but also reduce the amount of fertilizers, pesticides and other resources needed to grow these crops and thereby improve sustainability of the environment in which we live. Stay tuned for updates.

I hope you will find this issue informative and that it will expose you to the broad range of activities in our college. If we can be of service to you, or your company, or if you simply have an idea and you'd like to have some feedback, please feel free to contact us. We look forward to the interaction!

Dennis Helder, Ph.D.
Associate Dean for Research
Distinguished Professor of Electrical Engineering

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Waste material from machine shops holds the key to developing underground bioreactors that remove phosphates as well as nitrates from tile drainage runoff. Collaboration between assistant civil and environmental engineering professor Guanghui Hua and SDSU Extension water management engineer Chris Hay is helping farmers protect lakes and streams while increasing production. See story on pages 12-13.

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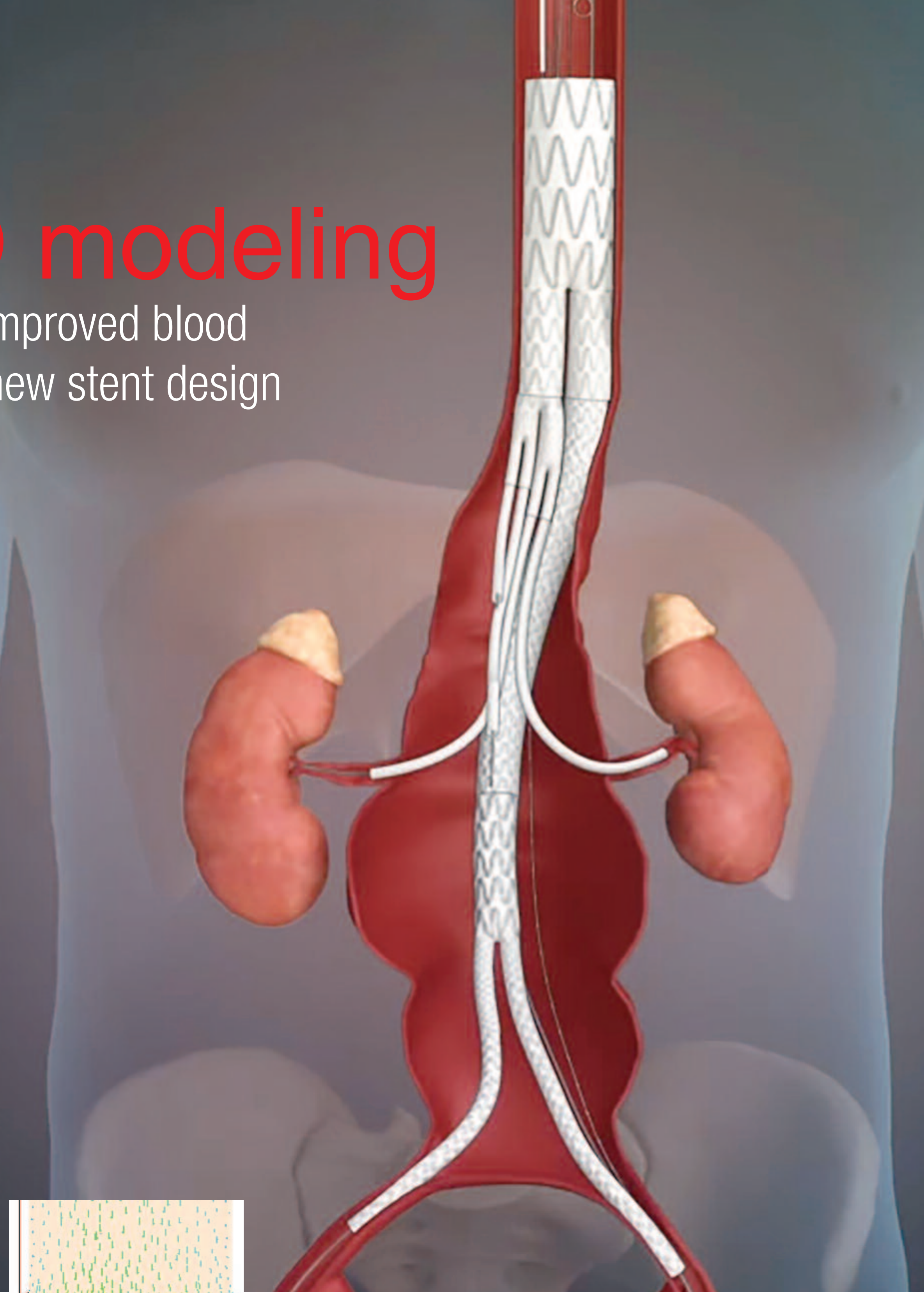
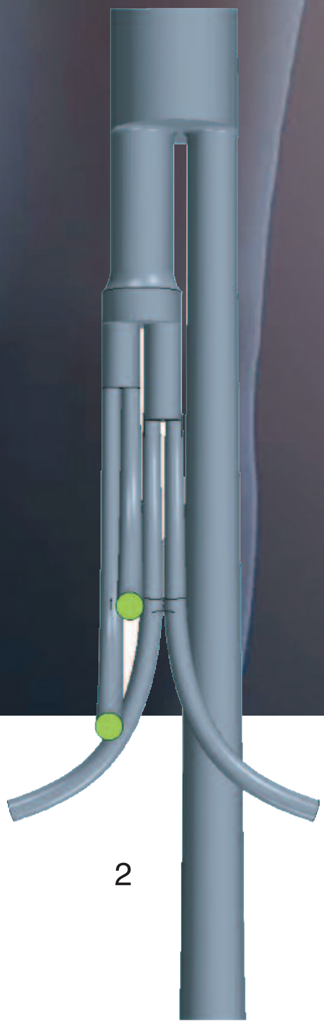
This publication is published by the Office of University Marketing and Communications

1000 copies printed by SDSU Office of Engineering Research at $0.00 each EG056 7-15

CFD modeling

confirms improved blood flow with new stent design





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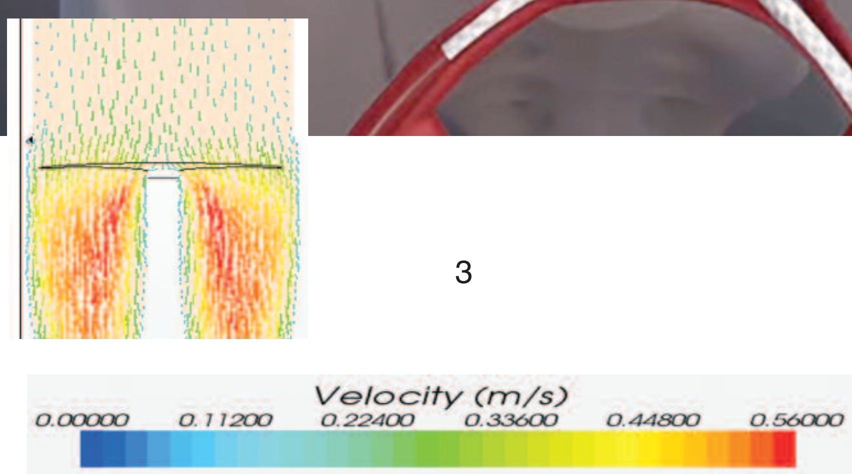

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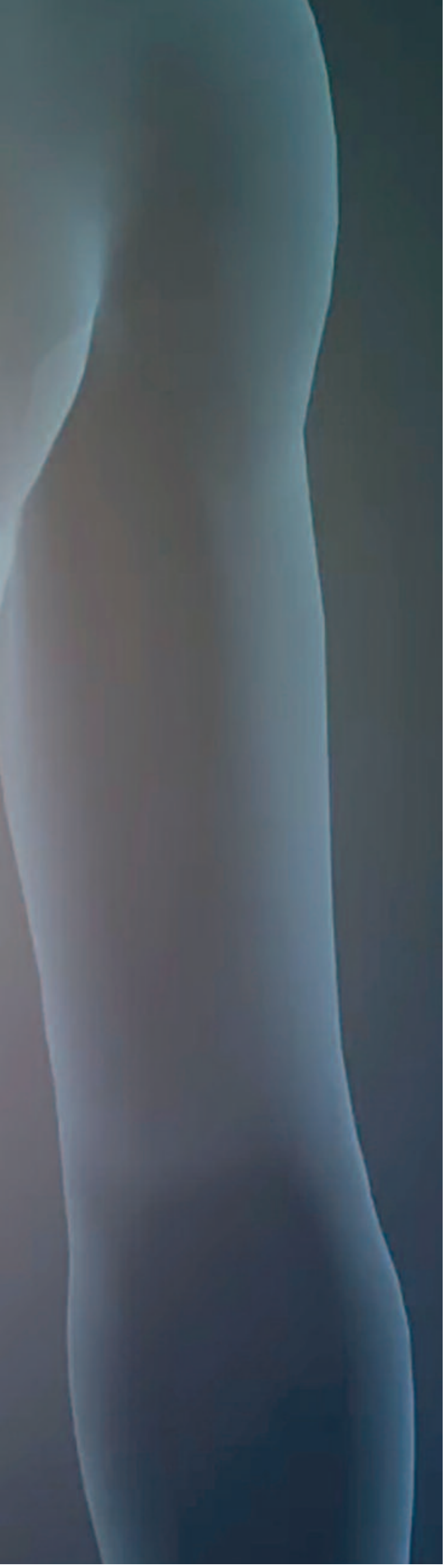

Vascular surgeon Pat Kelly of Sanford Health knew his patients were doing better with the stent graft he designed, but he wanted a better understanding of the mechanics before testing the device more widely in a clinical trial. For that, he reached out to SDSU.

Associate professor Stephen Gent in mechanical engineering had done computational fluid dynamics modeling for more than 10 years, but this was his first experience simulating blood flow.

Their research partnership has been a successful one.

The Sanford team began a Food and Drug Administration clinical trial on the device in March with the support of data from the computational fluid dynamics simulation and the patients Kelly treated. In April, Sanford signed a licensing deal with Medtronic that will bring this life-saving device closer to commercialization. The research was supported by a grant from Sanford Frontiers.

Setting up model

"This is not a trivial problem," Gent said, noting that blood is a pulsed flow. He and graduate student Taylor Suess used a commercially available computational fluid dynamics solver, Star-CCM+®, and wrote additional code to model blood flow through five stents. Three were commercially available, while two, including Kelly's, were new designs.

First, the researchers had to learn the medical terminology and then link the engineering results with what mattered to the medical professionals. "The language overlapped about 60 percent," Gent said, "but it helped that Kelly was a structural engineer before becoming a surgeon."

To compare the devices, Suess had to create a geometrically correct model of each graft relative to the same aorta coordinates and positioning in the body trunk and the arteries that feed the organs and extend into the legs. "I spent a significant amount of time modifying the CAD files to make the comparison as fair as possible," he pointed out.

Simulating blood flow

Simplified blood flow resembles a liquid moving through pipes from a fluids analysis perspective but, Suess pointed out, "the boundary conditions are intricate and the parameters aren't well-known."

To capture what was happening to blood flow near the artery walls where atherosclerosis tends to begin, the researchers had to write their own code. They had to consider oscillating shear index, time-averaged wall shear stress, relative residence time and wall shear stress temporal gradient.

"The longer the blood stays at one site, the greater the chance white blood cells will build up and cause thickening of the artery walls," Seuss said. That narrowing then increases the shear stress on the vessel wall.

Sanford biomedical engineer Tyler Remund, who is part of Kelly's product development team, explained the arteries that feed the kidneys are very prone to clotting. Remund earned his bachelor's in mechanical engineering from SDSU and then completed his doctorate in biomedical engineering at the University of South Dakota.

"The challenge that has faced the industry is keeping the renal vessels open," he added, noting that the short length and diameter of renal arteries leave them prone to narrowing once stented.

To account for the transient pulsatile flow of blood, Suess imported an extensive data table into the software that specifies the volumetric flow rate of the blood through the system every 5,000th of a second and outputs a solution every 1,000th of a second to make a simulation for a one-second cycle.

Traditionally, blood flow is modeled as a non-Newtonian fluid; however, the researchers found that these properties apply to arterioles and capillaries that are 1 millimeter or less in diameter. When Suess compared simulations using Newtonian and non-Newtonian fluid properties, he found "almost no difference."

Opening up opportunities

The fluid flow modeling "helped validate that the configuration is delivering more well developed blood flow with the design," according to Kelly.

"The simulation shows flow behavior next to the artery wall is more ordered, predictable and moderate with the design. It splits the blood flow upstream and lets it gradually come to the renals," he said. Gent and Suess confirmed this when they ran the computer simulations.

Only a small number of patients—two per 100,000 a year—are diagnosed with thoracoabdominal aneurysms, according to Kelly. However, most of these patients would not survive traditional open-heart surgery, which involves an incision from the chest to the groin .

"This less invasive approach could give more patients an option," Kelly pointed out.

This project could lead to more opportunities for the researchers. Gent accompanied the Sanford surgeon to a conference where Kelly presented the work they had done.

"We have a lot of options moving forward," Suess said. "We can do this type of modeling for any stent."

Stephen Gent

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Opposite: Sanford Health vascular surgeon Pat Kelly developed a stent graft that can be deployed inside blood vessels to help patients with thoracoabdominal aneurysms. Using computational fluid dynamics models, associate professor Stephen Gent confirmed that Kelly's design improved blood flow behavior.

2. This model of the stent graft Kelly designed was constructed using PTC Creo, a 3D CAD software package, and Star-CCM+®, a commercially available CFD solver package.

3. In this velocity vector model, brighter colors indicate blood flow acceleration as it passes through a bifurcation. CFD modeling provides insight on blood flow through and near the walls of the stent graft. Results can be used to compare the performance of stent graft designs and to minimize the probability of developing blood clots.

Statisticians evaluate probability models for

crime scene evidence

Bullet casings and shards of window glass recovered from a crime scene are enough to positively identify a killer—on the television series "CSI."

In reality, it's not that simple.

Forensic scientists deal more with probability than certainty when linking evidence to a particular person, according to assistant professor Cedric Neumann of the mathematics and statistics department. The Swiss native was head of the Forensic Science Service statistics and interpretation research group in the United Kingdom for five years and developed projects for the U.S. Secret Service for two years.

He led the Forensic Science Service team that developed and tested a statistical model to determine the probability that a specific fingerprint belongs to a particular suspect.

Neumann and assistant professor Chris Saunders are evaluating statistical models designed to determine probability values for evidence such as glass shards, fingerprints, bullets and handwriting through a three-year $780,300 grant from the National Institute of Justice. They are the first SDSU statisticians to receive such a grant.

The two have known each other professionally since 2006. Saunders did pattern recognition and handwriting identification as an intelligence community fellow in support of the FBI and the broader intelligence community for two years. He was an intelligence community postdoctoral research fellow at George Mason University for two years and worked on forensic evidence for the FBI in summer 2013.

Dealing with probability

"There is a strong movement to quantify the probability value of evidence to support the fairness and transparency of the criminal justice system," Neumann said. In 2009, the National Academy of Science cited the need to measure the probability value of evidence using statistical methods.

"We agree, but we're shooting in the dark," Neumann said. "We don't have a gold standard for what the probability value should be."

The first statistical models developed dealt with glass evidence, which can be easily described by random variables. "Developing such a model was relatively straightforward," he pointed out, particularly with the computing power available beginning in the 1990s.

However, the complexities of the statistical models, even for widely used DNA profiles, has increased. In the United States, forensic scientists compare the base pair sequencing at 15 loci plus gender to match a crime scene sample to a potential perpetrator or victim. According to the National Human Genome Research Institute, the human genome contains about 3 billion of these pairs.

"Early models relied on how many times that sequence is repeated in particular individuals," Neumann explained. However, in many cases, DNA gathered at a crime scene can come from multiple offenders and victims.

"Deconvoluting DNA mixtures can be challenging," he added. To determine which alleles belong to Mr. A or Mr. B, scientists developed complicated models that became increasingly difficult to manage.

"Different scientists have made assumptions or shortcuts to simplify those models and get something that could work," Neumann said.

Using different models, statisticians can come up with radically different probability values for the same piece of evidence, according to Saunders. "We have to find a way to determine the accuracy of these models."

Applying statistical models

The researchers are studying the convergence of these models to the true probability value by first using glass fragments for which they have known values from databases at the Forensic Science Center or the FBI. Doctoral students Danica Ommen and Douglas Armstrong started applying the models to glass fragments in spring 2015.

With what Neumann refers to as a "toy example," the researchers can define properties and conditions in the statistical models that ensure convergence to the expected values, knowing precisely what those values should be.

"What we have are the refractive index for each fragment as well as the elemental compositions for chemical elements, such as sodium, magnesium, aluminum and silicon," Neumann said. The statisticians will work backward to start from the expected probative value and develop models that converge.

"The main thrust of the work is formal use of the Bayesian paradigm for evidence interpretation, which is the gold standard for evidence quantification," Saunders explained. The difficulty lies in coming up with feasible computational measures to generate approximations.

In building an automated system for handwriting identification, Saunders pointed out, "The main goal is to get the right set of features that are relatively stable over time for a person."

Once the models produce acceptable results for the glass fragments, the researchers will apply those same conditions and properties to more complex evidence, such as handwriting, fingerprint and firearm identification.

"It's like throwing a knife and training the arm to go through the same motion each time," Neumann said. "Then we add the blindfold and hope we're still accurate."

The goal is to build a solid foundation for determining probability values that will help law enforcement agencies and the court trust forensic evidence.

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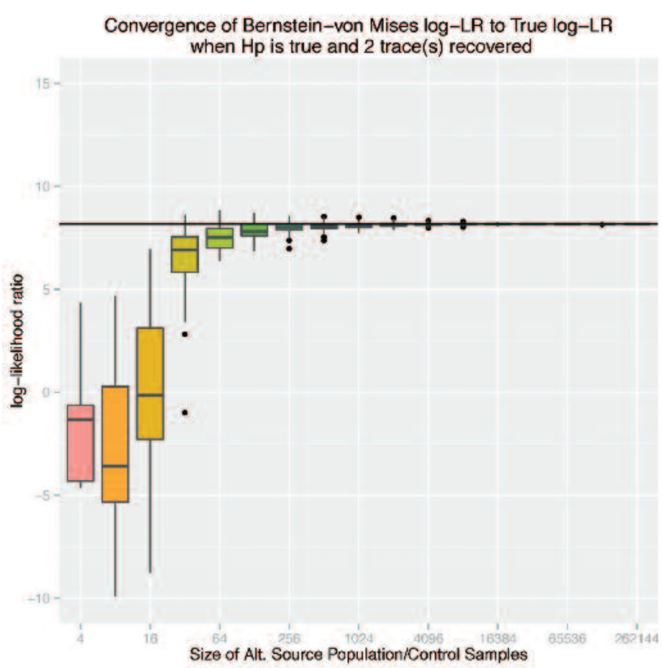
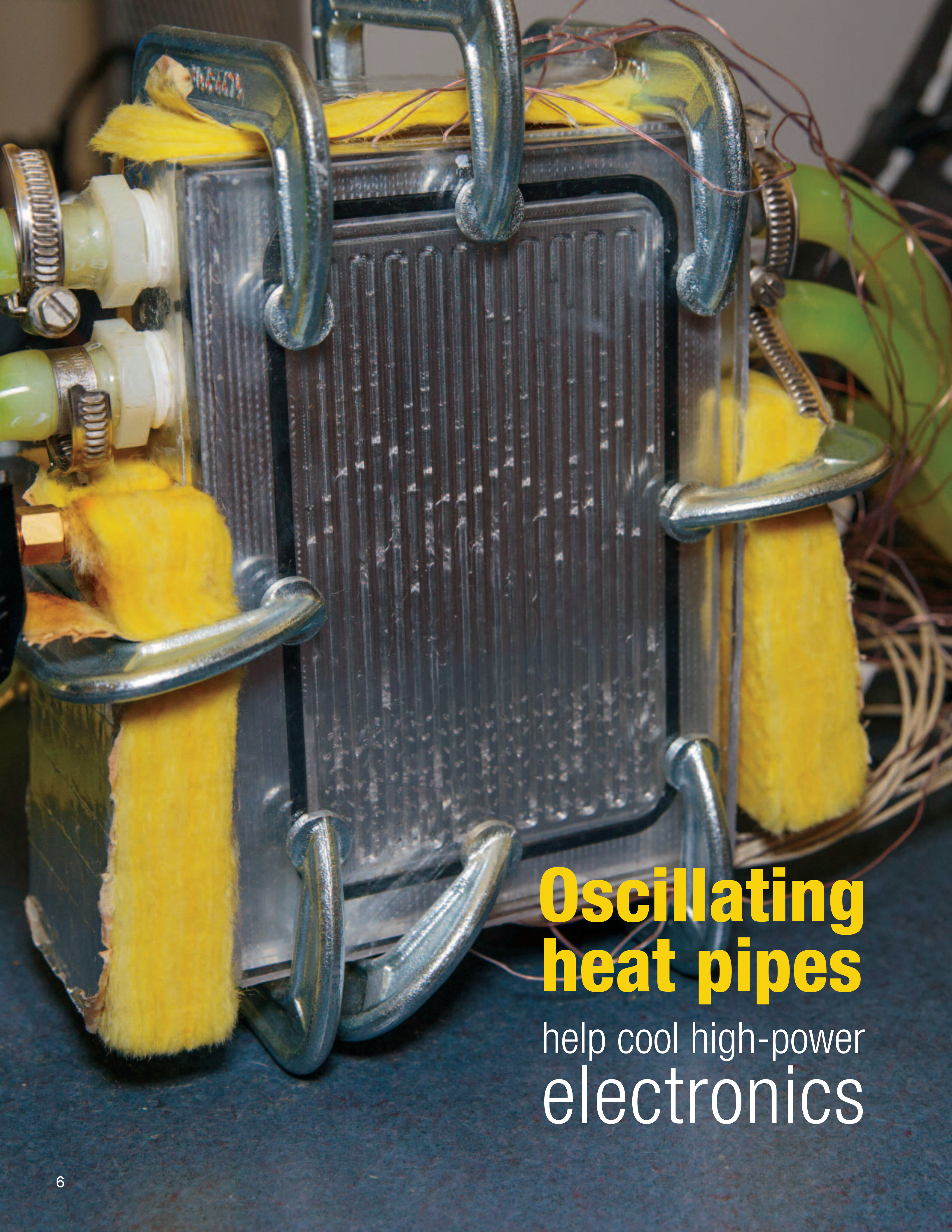


A series of boxplots tracks the convergence of a method to approximate the likelihood ratio based on the Bernstein-von Mises theorem. In this case, the likelihood ratio quantifies the probative value of two fragments of glass evidence recovered on a suspect's garment and linked to a broken window at a crime scene. The black line represents the true value of the glass evidence that needs to be estimated using samples of glass fragments. In a real case, this value would be an unknown. The likelihood ratio considers the likelihood that the observed fragments taken from the suspect's clothing came from the crime scene window vs. being deposited there by chance. Probative values above 0 (on the y-axis) connect the victim to the crime, while those below the 0 support the suspect's innocence. "As we increase the number of samples, and the closer we get to the black line, the higher the convergence of the estimate to the true value," said Neumann. The boxplot shows this method can approximate the targeted value and how many samples are needed to do this.



Oscillating heat pipes

help cool high-power electronics

Thermal management is a major limiting factor when it comes to developing smaller, more powerful electronic devices.

"Conventional cooling methods are not adequate for the faster, smaller processors," according to associate professor of mechanical engineering Gregory Michna. He is evaluating oscillating heat pipes as a more efficient, less expensive means of cooling high-power electronics, including handheld devices and laptop computers.

A single tube loops up and down accordion-style from the hot to the cool part of the device. "The idea is to capture heat on one end and release it on the other," he explained.

When the temperature difference between the hot and cool ends exceeds a certain threshold, fluid begins to oscillate in the thin tube. Thus, the passive system "doesn't draw power," Michna explained. "It can move a lot of heat without a power input and is cheaper to manufacture than traditional heat pipes."

However, the oscillations are driven by instability, which makes modeling the process difficult. Michna is the first SDSU researcher to do experimental work to determine which parameters affect the passive cooling system's performance. The project received nearly $100,000 in funding from the South Dakota Board of Regents.

Evaluating startup and performance

Graduate student Sagar Paudel, who completed his master's degree in May, looked at the behavior of oscillating heat pipes during startup and transient performance. He used a 20-turn oscillating copper heat pipe with an inside diameter of 1.58 millimeters outfitted with thermocouples. He applied heat using 26-gauge copper wire wrapped around the evaporator section.

Paudel experimented with three working fluids—water, acetone and methanol—and fill ratios ranging from 50 to 80 percent. In addition, he evaluated each fluid's performance at vertical and horizontal positions as well as a 45-degree angle to simulate the system's use in a laptop.

Water proved to be the best working fluid overall. When it came to startup performance, simulated by applying a 30-watt heat load, Michna said, "Water goes straight to the steady state temperature." Methanol and acetone resulted in overshoot, meaning the temperature exceeded the steady state temperature before the fluid began cooling the system.

"It's all about reliability, keeping temperatures low and consistent in electronic devices," he said.

To test transient behavior, Paudel varied the heat load from a low load of 10 watts and a medium load of 20 watts to a high of 30 watts at specific intervals.

Water worked best at a 70 percent fill ratio and high heat loads in a vertical position. However, it did not perform well in a horizontal orientation.

Acetone and methanol performed best at 50 percent fill ratio when faced with a high heat load. When challenged with a horizontal orientation, these two working fluids operated better with an 80 percent fill ratio.

Designing a heat sink

Graduate student Mitchell Hoesing, who began work on the project as a senior, is modifying the geometry of the evaporator section to enhance the heat transfer using a 4-inch by 7-inch experimental model.

The flat aluminum plate model has an oscillating heat pipe milled into its surface with a glass cover to allow the fluid flow to be visualized. The aluminum plate acts as the heat sink, transferring heat from a simulated CPU to a liquid-cooled block.

During initial testing, Hoesing switched the working fluid from water to acetone because the water reacted with the aluminum to produce a noncondensible gas. "It actually limited the oscillating flow within the system," he said.

Hoesing is evaluating two modifications to the heat sink design. First, he's inserting pin fins in the channel to increase the surface area and promote flow mixing. However, the fins increase the pressure drop in the evaporator section, which can negatively impact fluid oscillation.

"The trick is to get a geometry that increases the heat transfer more than it increases the pressure drop," he added.

The second modification uses small re-entrant cavities on the sides of the channel oriented to encourage the fluid that typically oscillates to flow in a single direction. This more regular flow pattern may increase the heat transfer.

Laying groundwork for the future

Each oscillating heat pipe cooling system will have to be designed for a specific heat load, according to Michna. "Knowledge of how much power needs to be dissipated from what surface area and at what temperature all figure into the design."

He will use the experimental results to apply for a National Science Foundation grant. Though oscillating heat pipes have the potential to transfer up to 100 times more heat than conventional heat pipes, according to Michna, researchers are only beginning to understand how this passive cooling system works.

Gregory Michna

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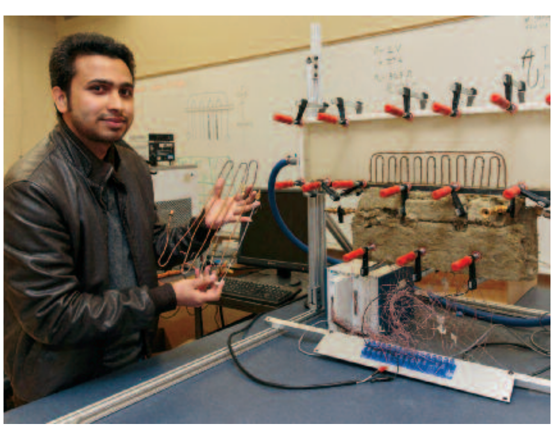
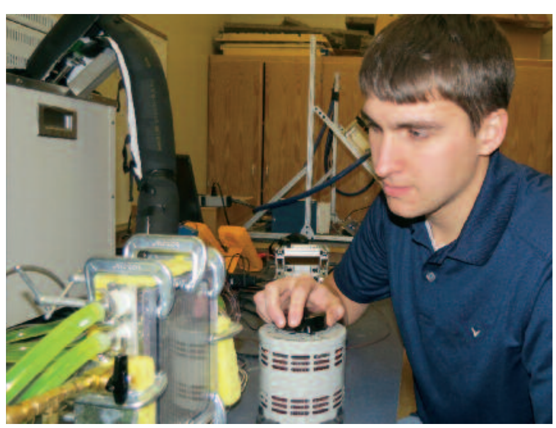
Opposite Tiny vapor bubbles and liquid slugs move up and down within the capillary-scale tube of the 4-inch by 7-inch experimental model. Oscillations occur when the temperature difference between the hot and cool ends exceeds a certain threshold.





Left: Using the larger 20-turn oscillating heat pipe model, graduate student Sagar Paudel investigated the behavior of oscillating heat pipes during startup and under nonsteady state conditions. He completed his master's degree in May 2015.

Right: Graduate student Mitchell Hoesing will determine whether geometric design modifications can increase the amount of heat that the oscillating heat pipe can dissipate from a small electronic device.

“The issue of improving the performance of double-tee bridges is of great interest to state and local governments and the local precast concrete industry.”

Nadim Wehbe

Bridge girder

Grid connection method improves double-tee girder performance

A new grid method of connecting double-tee girders makes the longitudinal joint outlast the bridge girder, according to research done at the Jerome J. Lohr Structures Lab.

The two-year, $160,000 research project was sponsored by the U.S. Department of Transportation through the Mountain Plains Consortium and the South Dakota Department of Transportation, which provided more than half of the funds.

"The issue of improving the performance of double-tee bridges is of great interest to state and local governments and the local precast concrete industry," said structures lab director Nadim Wehbe, who led the research project. The John M. Hanson Endowed Professor in Structural and Construction Engineering is also head of the SDSU Department of Civil and Environmental Engineering.

Michael Konrad, who completed the research as part of his master's program at SDSU, said, "The longitudinal joint is no longer the weakest link; it's very robust."

The American Association of State Highway and Transportation Officials recognized the new girder design as one of the top 16 high-value research projects in the nation.

Gage Brothers of Sioux Falls and Cretex of Mitchell helped the researchers redesign the girders. "I am always pleased to see the research infrastructure at State continue to serve the needs of our constituencies," Wehbe added.

Fulfilling local bridge needs

Double-tee girders are commonly used for short-span bridges because they can be installed quickly, according to Joshua Olson, region bridge engineer at the South Dakota Department of Transportation in Aberdeen. Unlike an I-girder, the double-tee has a riding surface built into the girder, so bridge construction takes less time—the road might only be closed for two months, rather than an entire summer.

Short-span bridges are widely used in South Dakota. The state has 3,981 local bridges on city and county roadways that span an opening of 20 feet or more, according to Doug Kinniburgh, local government engineer at the South Dakota Department of Transportation.

A typical bridge on a secondary road would be eight girders wide with seven longitudinal joints, according to Konrad. The research project focused on 40-foot precast girders, the most commonly used bridge length.

Improving the connection design

The conventional joint design calls for 6-inch long steel plates to be welded to 6-inch long steel angles that are embedded in the girders every 5 feet along the joint to secure the two sides. Nonshrink grout is used to fill the 1.5-inch gap between the girders.

Repetitive loads from trucks passing over the bridge wreak havoc on the welded steel connections, Konrad explained. The steel plates act like hinges which do not provide adequate load transfer between the girders. This causes the grout to crack, allowing water to leak through the joint. Over time, the reinforcing steel in the girders corrodes and the concrete starts to deteriorate prematurely.

The experimental girder design uses a reinforcing steel mesh in the connection that runs the length of the girder with a 4-inch gap between the girders, which is then filled with non-shrink grout. Konrad supervised the building and instrumentation of the four girders, which Cretex provided at cost.

Comparing fatigue load performance

Two fatigue loading conditions were applied to determine performance of the conventional and experimental girders. A 42-kip cyclic load was applied to simulate overload truck traffic on a rural county road and a 21-kip cyclic load to simulate normal load truck traffic. One kip equals 1,000 pounds-force. The loading was applied at one load cycle per second.

When the 42-kip load was applied to the conventional girder design, the

Continued next page.

Nadim Wehbe

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Left: Civil engineering graduate students Michael Konrad and Walker Olson prepare to align the second experimental girder with the first one.

Commonly used for short-span bridges, these girders get their name from the double-tee formation when they are positioned side-by-side.

continued from page 9

first weld failed at 31,500 load cycles or 5.8 years of service, according to Konrad.

When the first plate cracks, the load shifts, he said. "It's like a zipper effect." The last of the four welds failed at 56,000 cycles, approximately 10 years of service, and the test was stopped.

The new experimental design withstood 100,000 load cycles at 42 kip without any changes in performance.

Under the 21-kip load conditions, the first welded connection of the conventional girder failed at 62,000 cycles and the last at 80,000 cycles. The new experimental design was subjected to more than 800,000 loading cycles with no signs of failure. The researchers estimated that a 75-year design life would be equivalent to 410,625 cycles under average South Dakota traffic conditions.

Even after testing to simulate 146 years of service, the experimental structure did not fail, Konrad pointed out. The experimental design reduced the rate of stiffness degradation by 96.5 percent for 21-kip fatigue loading and 99.5 percent for 42-kip loading tests when compared to that of the conventional design.

Testing strength to failure

To test the strength of the conventional and experimental girders after fatigue loading, the researchers applied a monotonic load until failure. The conventional bridge setup failed at 73,800 pounds of force, while the experimental design succumbed at 113,100 pounds of force.

"The girders failed, not the joint—that's what we wanted to see," said Konrad.

Olson, who came with two South Dakota Department of Transportation colleagues to watch the experimental girder strength test, said, "The results were dramatically better."

The cost of replacing a 20- to 50-foot bridge ranges from $300,000 to $700,000, depending on its length, according to Olson. Michael Asmus, president of Holloway Construction Company Inc. in Mitchell, estimated the new design increased installation costs by 3.5 percent, Konrad explained. For this extra investment, taxpayers could get a bridge deck designed to last twice as long—more than a century.

Project results were submitted to the research office at the South Dakota Department of Transportation. The results will be reviewed by the project's technical panel before they are presented to the department's research review board. The process generally takes a year or two, Olson said, "but this one may be fast-tracked."

SELF-CONSOLIDATING CONCRETE

Konrad smoothes the grout that structures lab manager Zach Gutzmer pours into the longitudinal joint of two double-tee bridge girders.

Olson, left, marks each of the cracks in the girder that develop during the final testing-to-failure phase.

Konrad documents the areas of the girder that succumb during failure testing. During the testing-to-failure phase, the researchers used a strength test applying an increasing load to the experimental girder structure.

Civil engineers help formulate recipe for Wisconsin prestressed bridge girders

It's a special recipe, but it doesn't involve chicken or baked beans.

Before Wisconsin precast manufacturers can begin building prestressed bridge girders using self-consolidating concrete, the Wisconsin Department of Transportation must determine the optimum mixture of locally produced aggregates, cement and water. That's where assistant civil engineering professor Junwon Seo and the Jerome J. Lohr Structures Laboratory can help.

ConcreteNetwork.com called self-consolidating concrete "one of the greatest advances in the concrete industry over the past 20 years." It flows easily around intricate forms including rebar without separating and leaving voids.

"Each state has different aggregate," Seo said, which is why the self-consolidating concrete mixture specifications from other states cannot be appropriately used. The project is supported by a two-year, $70,000 grant from the Wisconsin Department of Transportation. Work began in November 2014.

After reviewing specifications from other states, Seo worked with Wisconsin DOT officials to determine target values and acceptable ranges for material properties testing.

This spring Seo and graduate student Eduardo Torres performed slump flow, J-ring and L-box, VSI and column segregation tests to evaluate fresh experimental mixtures made with constituents from Wisconsin. Their goal is to determine the appropriate mixture of small and large aggregates, cement and water, as well as admixture.

The researchers will ascertain the material properties of the mixture—compressive strength, modulus of elasticity, flexural strength, creep and shrinkage—through hardened property testing in the structures lab. Once they optimize the mixture, they will repeat the tests at three Wisconsin sites to confirm their findings.

After the researchers establish the design mix recommendations, they will evaluate its implementation ability using prestressed bridge girders made with the mixture.

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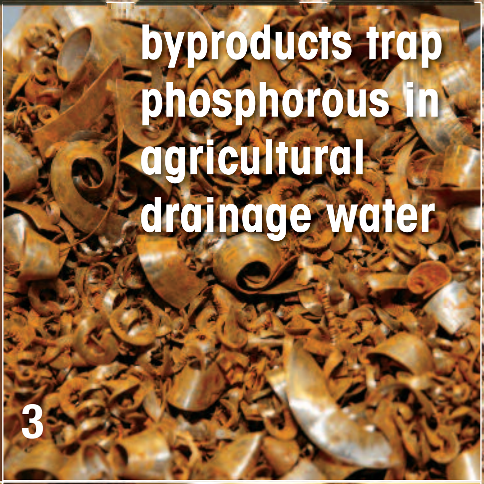
Opposite left to right: Graduate student Eduardo Torres performs a slump flow test to evaluate the stability and the flow of a self-consolidating concrete mixture using Wisconsin aggregates.

The J-ring test then helps Torres evaluate the passing ability of the concrete mixture, which will be used to make prestressed bridge girders. The mixture should spread out to a 25-inch radius.

Graduate student Luke Rogers assists Torres with column segregation testing of the concrete mixture while assistant professor Junwon Seo takes photos to document their work.

STEEL

byproducts trap phosphorous in agricultural drainage water



The nitrogen and phosphorous that nurture crops become pollutants when they drain into lakes and streams. Wood chip bioreactors have proven useful in removing nitrates from tile drainage water, but researchers are still searching for low-cost methods of removing phosphates.

Assistant professor of civil and environmental engineering Guanghui Hua is using steel byproducts to trap phosphates in simulated tile drainage water. He collaborates with assistant professor of agricultural and biosystems engineering and SDSU Extension water management engineer Chris Hay, who has been testing wood chip bioreactors since 2011. Hay envisions installing a steel-containing cartridge as an add-on to nitrate-capturing bioreactors.

Their research is supported by a U.S. Geological Survey grant through the South Dakota Water Resources Institute with matching funds from the East Dakota Water Development District, SDSU Water and Environmental Engineering Research Center and the Department of Civil and Environmental Engineering. The project, which began in March 2014, has received $140,653 in funding.

Protecting lakes, rivers

"This research is very timely," said Jay Gilbertson, manager of the East Dakota Water Development District. "There's a lot of upside to agricultural drainage, but like anything, there is no free lunch."

Though drainage water looks clear and clean, Gilbertson said it often has elevated nitrogen and phosphorous levels. "Doing something to address this nutrient-loading issue will help offset some of the negatives."

In 1996, the Lake Poinsett Watershed Strategic Plan reported "a strong relationship between in-lake total phosphorous and severe algal blooms" and set goals to reduce blue-green algae in the lake.

"Phosphates are the leading cause for algae growth in natural water bodies," Hua pointed out. Because dissolved phosphorous is readily available, algae can use it easily, Hay added. "A little bit can lead to algal bloom."

In addition to consuming oxygen, some algae species release toxic substances into the water, Hua explained. When dead birds and animals were found near the shores of Pelican Lake near Watertown in June 2014, the South Dakota Department of Environment and Natural Resources issued a warning about the potential danger from algae toxins in the stagnant water.

In the last decade, more South Dakota farmers have installed tile drainage to increase crop production, particularly in the last five years, Hay explained. Tile drainage generally reduces total phosphorous losses from farmland, which helps reduce phosphorous loading to lakes and streams. However, the drainage can still be a source of dissolved phosphorous, which is what this research addresses.

Experimenting with steel byproducts

Hua and graduate student Morgan Salo are testing four types of steel byproducts to determine their phosphate removal capacity. "These materials are low cost and readily available for agricultural application," Hua said, noting they gathered the waste materials from machine shops in Sioux Falls.

When the steel shavings rust, the phosphate ions bind to the oxidized iron surfaces, removing the phosphates from the drainage water.

"The steel byproducts have proven very effective," Hua said. The researchers performed batch adsorption tests to determine the maximum capacity on a per mass basis for each type of steel material.

Carbon steel works better than stainless steel, Hua pointed out, noting that the iron oxide on carbon steel surfaces is highly reactive with phosphates. The researchers selected a steel mixture containing small and large pieces for subsequent reactor experiments.

They are now optimizing the procedure by pumping simulated drainage water first through a column filled with wood chips and then one filled with steel byproduct in an upflow reactor.

The simulated drainage water contains 20 milligrams per liter of nitrate, 1 milligram per liter of phosphate and small amounts of sodium sulfate, calcium, magnesium, potassium and trace metals. The system contains three times more wood chips than steel.

The civil engineering researchers are evaluating a 24-hour flow time through the wood chips and eight hours through the steel byproduct. During three months of continuous operation, the column reactors consistently exhibited 100 percent removal of nitrates and phosphates.

In addition, they are exploring factors such as varying flow-through time and influent nutrient concentrations using the column reactors. The researchers will also conduct batch experiments to determine the impact of pH, temperature and reaction time on adsorption.

Hua expects to complete the batch column experiments by December.

Moving to field trials

In the bioreactor, water will flow through a bed of wood chips first and then a steel-loaded barrel before entering the last control structure, according to Hay. An underground bioreactor in the neighborhood of 15 to 20 feet wide and 100 to 120 feet long can handle the runoff from a 30- to 40-acre field.

The researchers plan to add a phosphorous unit to a wood chip bioreactor at Baltic this fall through funding from the South Dakota Soybean Research and Promotion Council. The goal is to remove 80 to 90 percent of the phosphates and nitrates from the tile drainage water.

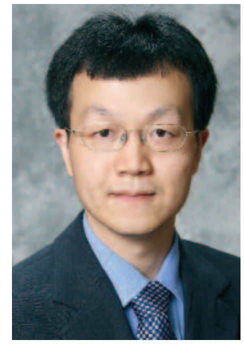
Certain combinations of soil and management factors can increase the potential for phosphorous to reach tile lines, Hay explained. This research provides a way to remove that phosphorous before it reaches the surface water.

Gilbertson called the two-stage bioreactors "a very good thing for the agricultural community."

In March, the Des Moines Water Works, which provides drinking water to more than half a million people, filed a federal suit against three counties and 10 drainage districts because of increasing nitrate levels in the Raccoon River. "If that suit is successful, the implications will be staggering," Gilbertson added.

South Dakota has not yet experienced problems of that magnitude, but he pointed out that Sioux Falls, which takes its drinking water from the Big Sioux River, "is looking north with trepidation."

This research will help farmers reduce the potential impact of tiling on water quality.



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Opposite: Wood chip bioreactors, such as this one being installed in Baltic, are capable of removing nitrates in tile drainage water, but thanks to a collaborative research project involving assistant professors Guanghui Hua of civil and environmental engineering and Chris Hay of agricultural and biosystems engineering, these bioreactors may one day also be able to remove phosphates.

Inset photos left to right:

1 Using an upflow reactor, researchers are determining the flow-through time necessary to remove nitrates using woodchips in the left column and then phosphates with steel shavings in the right column. The aluminum foil prevents light from entering the columns to simulate the underground bioreactors.

2 Graduate student Morgan Salo takes a water sample from the column that contains steel shavings.

3 The iron oxide on the surface of this mixture of small and large carbon steel shavings is highly reactive with phosphates.

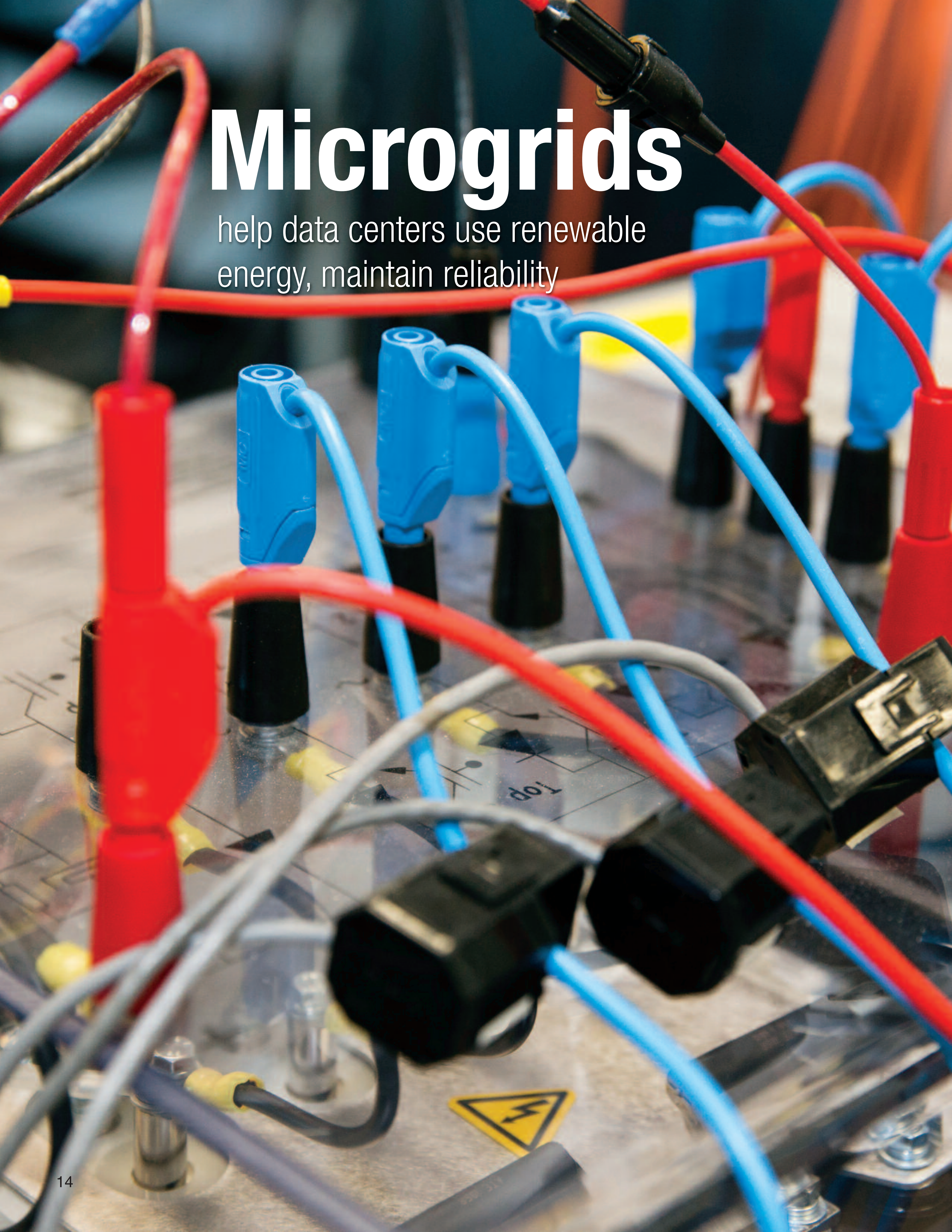
4 Salo filters samples collected from the column reactors for nitrate and phosphate analysis.

5 Undergraduate Kody Weiss adds nanopure water to dilute a sample for dissolved organic carbon analysis.

6 Salo, right, adds hydrochloric acid to preserve the sample and then Weiss will top off the sample with nanopure water and cap it until they are ready to do the dissolved organic carbon analysis.

Microgrids

help data centers use renewable energy, maintain reliability



Use of renewable energy can reduce power costs and enhance the resiliency and sustainability of data centers, but engineers must first develop ways of integrating locally produced energy without jeopardizing reliability.

Through a grant from the Microsoft Corporation, assistant professors Wei Sun and Reinaldo Tonkoski of the electrical engineering and computer science department are developing a microgrid that will allow data centers to use locally produced energy while maintaining a consistent, reliable power flow. They are the first SDSU engineering researchers to receive a Microsoft Software Engineering Innovation Foundation grant.

In 2010, U.S. data centers consumed about 76 billion kilowatt-hours of electricity, or about 2 percent of the electricity used nationwide, according to research from Stanford University. The growth of cloud computing, in which businesses and individuals access software and computing services through the Internet on an external server, has spurred the growth of data centers, such as those used by Microsoft Azure.

The project is part of Microsoft's effort to reduce its carbon footprint and to lower production costs by using renewable energy to power its data centers.

Addressing reliability

"Data centers are high consumers of power," Tonkoski said, "but that supply has to be really reliable." Most centers rely on the main power grid, meaning electricity from power plants, commonly generated using fossil fuels.

"Although alternative energy sources can reduce their reliance on the power grid," Sun pointed out, "renewables have uncertainty." Solar and wind power production varies based on time, cloud conditions and wind speed, so integrating them into the distribution system means solving problems such as maintaining power system balance, explained Tonkoski.

"Typically, data centers are designed with a lot of storage or backup capability so if something happens in the power grid, other energy sources will take over," Tonkoski explained.

Locally produced power can come from generators fueled by diesel or natural gas, batteries or renewable energy sources, such as wind or solar, depending on what's available, Sun explained.

Adding solar or wind energy can save fuel and reduce the load on the generator. "Integrating batteries into the system may boost the efficiency of the generator," Tonkoski added. Two doctoral students and 12 master's students are working on power management and renewable energy systems integration in the SDSU microgrid laboratory.

Simulating solar power integration

The researchers ran simulations to determine how much solar energy can be integrated into remote power systems without jeopardizing reliability. The power management system uses specially designed controllers combined with new battery technologies.

Tonkoski simulated a microgrid that integrates a 27-kilowatt solar panel with two diesel generators—one 30-kilowatt and one 75-kilowatt—and a 170 kilowatt-hour lead-acid battery. The model, which is based on a similar microgrid operating in a remote North American community, is designed to take care of an average load of 25 kilowatts.

To do this, the team developed a controller to schedule and dispatch the energy sources and coordinate the power sharing among the generators and battery while optimizing the operation of the microgrid. The researchers were able to improve battery life from less than a year to more than 7 years and reduce operation costs by 16 percent.

The simulation used a deterministic model in which the output is determined by the parameter values and initial conditions to schedule resources. Subsequent simulations will determine whether stochastic methods that account for the unpredictability of renewable energy sources will produce better results. This portion of the work is supported by South Dakota Board of Regents grants.

Creating a virtual power plant

A power management algorithm operates the microgrid as a virtual power plant, which not only minimizes operation costs but also improves power quality. Once fully developed, this autonomous power plant could ultimately sell energy back to the grid.

With data centers being built worldwide, Sun noted, "some regions do not have a robust power grid." Therefore, construction of a new data center and the infrastructure to handle a power load in the range of 100 megawatts can take as long as three years.

"Using multiple energy sources through a microgrid system may reduce the timeline to establish new facilities," Tonkoski said.

Looking long term, Sun also anticipates that self-healing microgrids, which he worked with at the Electric Power Research Institute in 2011, offer an opportunity to "increase system resiliency." Specialized restoration management software can insulate facilities against possible outages by automatically switching power sources.

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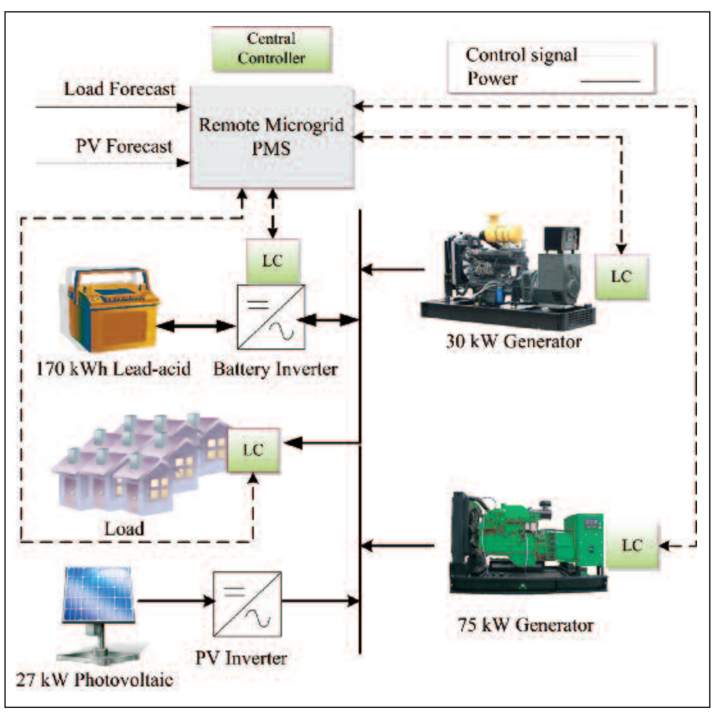

This simulated microgrid uses a solar panel, two diesel generators and a battery to take care of an average load of 25 kilowatts. Using a controller to manage the power, the researchers increased the battery life to seven years and reduced operation costs by 16 percent.

AWARDS

Two engineering researchers receive awards

Stephen Gent

Young Investigator Award goes to mechanical engineer

The flow of corn kernels through a drying bin and blood through arteries seem worlds apart, but associate professor Stephen Gent of the mechanical engineering department has modeled both processes. The Jerome J. Lohr College of Engineering recognized Gent with its Young Investigator Award, which provides $1,000 to support his work.

Gent, who has been at SDSU since 2009, has been working on computational fluid dynamics modeling for more than 10 years. Each summer, he oversees students working with fluid flow modeling through the National Science Foundation Research Experience for Undergraduates that SDSU hosts. He serves as the associate program director for the 8-week program that brings 10 science, engineering and mathematics students from across the nation to campus.

Gent and colleague Mike Twedt collaborated on a project to increase the efficiency of corn dryers for Brock Grain Systems of Frankfort, Indiana. Gent developed three increasingly accurate and sophisticated numerical models and validated them experimentally.

He recently took on the challenge of modeling blood flow through stent grafts for Sanford Health vascular surgeon Pat Kelly and his development team. The data from the simulation helped Kelly secure approval for a Food and Drug Administration clinical trial and a licensing deal with Medtronic for his thoracoabdominal aneurysm stent graft (see story on page 2). The collaboration helped Gent find other research opportunities in the medical field.

Chris Schmit

Water research center director recognized as outstanding researcher

Professor Chris Schmit of the civil and environmental engineering department received the Outstanding Researcher Award for the Jerome J. Lohr College of Engineering at the university's 2015 Celebration of Faculty Excellence. He is the director of the SDSU Water and Environmental Engineering Research Center.

For more than a decade, he has done research for the Sioux Falls Water Reclamation Facility. In 2010, a filtration project saved the city an average of 1 million gallons of water per day and reduced labor and energy costs by about $12,000 per year.

More recently, he worked on a wastewater filtration project with John Morrell that confirmed that the media being used was the best choice.

At the research center, Schmit oversees testing that allows utilities and commercial companies to document that they are meeting the minimum standards for wastewater discharge and drinking water quality. In addition, through an agreement with the City of Brookings, he provides opportunities for students to operate and evaluate treatment at the Brookings Wastewater Treatment Facility.

Grantswinship award winners recognized

Faculty members in the Jerome J. Lohr College of Engineering who secured or had research expenditures of $100,000 or more during the 2014 fiscal year are first row, Sharon Vestal and Suzette Burckhard; second row, Qiquan Qiao, John Puetz, Nadim Wehbe and Ross Abraham; third row, Chris Schmit, Xiao Qin, Fereidoon Delfanian and Greg Michna; and fourth row, Ken Skorseth, Richard Reid, Sung Shin and Stephen Gent. Not pictured are David Galipeau and Dennis Helder.

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