Creation of Heat Transfer and Friction Factor Correlations for a Pin Fin Array

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UTSR Fellowship Summer 2008

at Siemens Energy, Inc., Orlando FL

Acknowledgments:

Being able to spend the summer working with the Engineering Staff at Siemens Energy, Inc. has been a privilege. I would like to especially thank Mr. Mazzola and Mr. Mhetras for all the help and guidance they provided me throughout the summer, as well as making my stay extremely enjoyable. My time spent working with professionals in the Engineering Industry has not only reinforced my decision to pursue a career in the Engineering Field, but has also instilled me with a much greater passion which has inspired me to take my education to the next level as well as extend my time with Siemens as an intern while I pursue my Master's Degree.

In addition I would like to thank Dr. Kapat for making me aware of this great opportunity and helping me prepare for this and many other tasks. Thank you as well to all of the personnel at the South Carolina Institute for Energy Studies and the Department of Energy for making the UTSR Program available to students.

Introduction:

This report is a summary of the work done over the summer through the UTSR Fellowship Program at Siemens in Orlando, FL. The work done here, and by other students participating in the program was to meet the overall goal, namely to increase the energy security of America while also providing a cleaner environment. This means not only increasing power generation efficiency, but also reducing emissions as much as possible.

The main focus of this project was to create Heat Transfer and Friction Factor correlations from data generated in a Research Lab, which could later be applied to other designs. By providing designers with stronger heat transfer correlations, which could lead to a more highly optimized cooling scheme for turbine components this project could lead to a slight overall reducing in required cooling air for the turbine as a whole. This would naturally lead to an increase in engine efficiency as less air is wasted for cooling purposes and more can be combusted, providing a higher output of the power plant.

The project was broken down into three major components. The first step was to check and analyze the data provided by Mark Ricklick from the Center for Advanced Turbine and Energy Research (CATER) under the direction of Dr. Kapat, at UCF. The second step consisted of actually coming up with the correlations and making sure that they accurately represent the data with all variables taken into account. Finally the correlations were validated against the measured data along with other correlations from literature. It is important to note that due to confidentiality it is impossible to present the project in very much detail.

Step 1: Checking the Data

Before begging any of the correlation creation, the data received from the Research Lab had to be looked over and checked. This was extremely important since data with even slight errors could actually skew the correlations pretty heavily. To weed out any major errors all of the data points were compared to each other to create general trends, any points that did not match the trends were noted. Next the data was compared to other data from VanFossen and Chyu which was provided by the lab. Again trends were established and any points that did not match the trend were marked. Not many points were found to be outside of the established trends, but after recalculating some of the numbers, all but one of the discontinuities were resolved. That one point was later discarded and treated as an outlier.

Even though this first step was relatively time consuming it was extremely interesting for me. This was mainly due to the fact that before accepting the UTSR Fellowship I actually worked as a Research Assistant for CATER. Now I was provided with the unique opportunity to work with all the people I had been working with for years, but from the other side of the fence. Instead of working for the University doing research for the Industry I was now part of the Industry working with the University.

Step 2: Creating the Correlations

Once the data was checked it was time to come up with the correlations. For the project a total of four different correlations needed to be generated: one for the Heat Transfer on the Endwalls, one for the Pins, one for the Sidewalls and finally one for the Friction Factor. To get a starting point the correlations form VanFossen and Chyu were looked at to get a general idea of the form that the correlations would take on (at least for the Heat Transfer Correlations). VanFossen and Chyu's correlations are provided below:

- VanFossen: $Nu = 0.153\,\mathrm{Re}_{VF}{}^{0.685}$
- Chyu: $Nu / \mathrm{Pr}^4 = a * \mathrm{Re}_{Ch}{}^{b}$

Even though VanFossen's and Chyu's correlation provided a good basic starting point, there were more variable parameters present here which served to add more terms, and complicate the correlations quite a bit. Naturally the creation of the first of the three Heat Transfer Correlations was the most challenging, since this laid the general framework for the other two. Meaning that once the form of the equation was laid out from the first correlation the others mostly just required new coefficients to be found. Most all of the correlation creation process was done in excel with countless optimizations to ensure that the best possible match was found for all cases. The Friction Factor Correlation was created in much the same way, but due to the fact that I did not find a good sample to work with I didn't have as good as a starting point as I did for the Heat Transfer Correlations. Regardless, once the initial form of the equation was defined, many optimization runs led to the final product.

Plots of correlated vs. measured data for all four cases are provided as a reference in the appendix.

Step 3: Validation

After all the correlations were created they needed to be checked to make sure that they do in fact accurately represent that data, and are usable for future cases. This was done two ways. First all of the correlations were extrapolated out beyond the range of the data for all variables. This was done to ensure that the correlations don't just hold for this given data set, but can be applied to any number of data sets, even at vastly different conditions.

Finally the correlations were validated against the ones from VanFossen and Chyu, and the Dittus Boelter relationship. To do this all of the correlations were applied to the measured data and then plotted. The main difficulty associated with doing this is that both VanFossen and Chyu, as well as the measured data all had different ways of defining Reynolds number and Hydraulic Diameter. To cope with these differing definitions hydraulic diameter ratios were created and then used to scale both the measured Nusselt and Reynolds numbers. After this was done the respective correlations could be directly applied to the scaled numbers. It is important to note that this step was not done for the Friction Factor Correlation as neither VanFossen nor Chyu provided Friction Factor data.

Once both the extrapolations and literature validations were complete they were all plotted. Extrapolations were plotted together based on what variable was being extrapolated, and as mentioned before the validation plots were kept together to better analyze them. As expected the extrapolated curves all maintained the same trends regardless of weather or not the data was part of the measured or extrapolated values. In addition to this all four plots on each of the validations graphs were very close to each other throughout all of the measured data. Therefore it can be concluded that the correlations accurately represent the measured data and are acceptable.

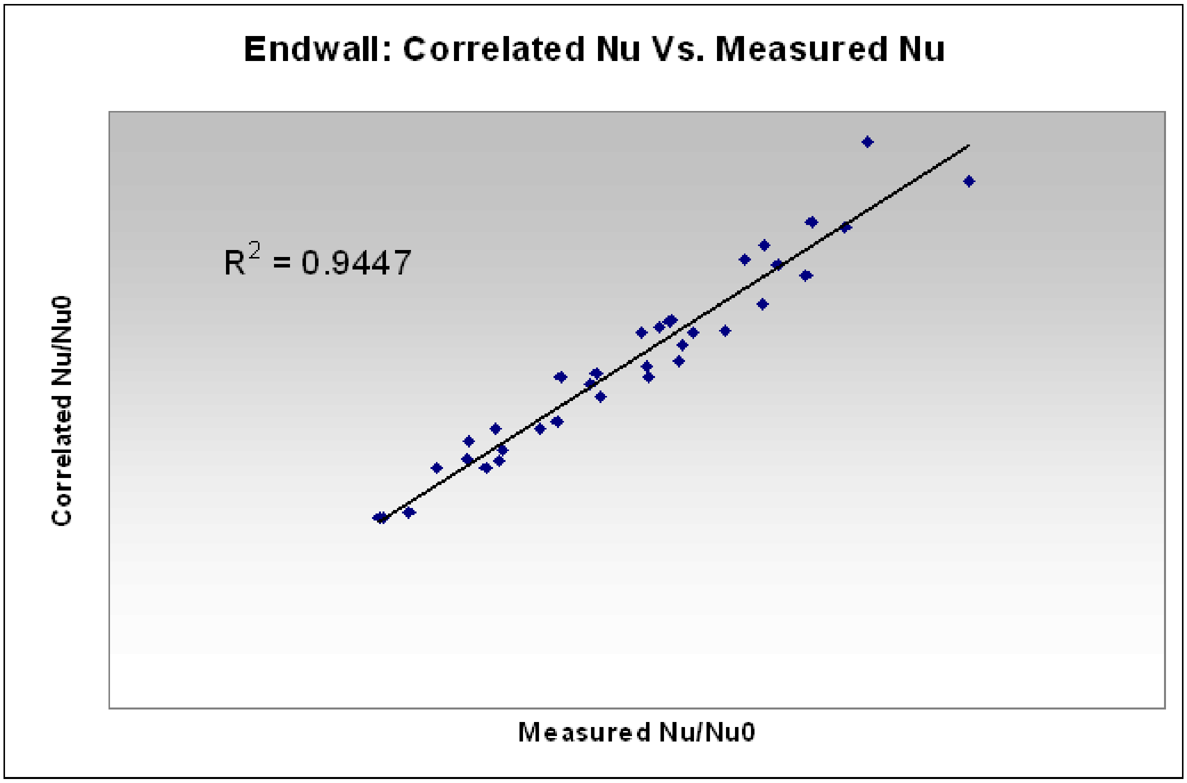
Summary

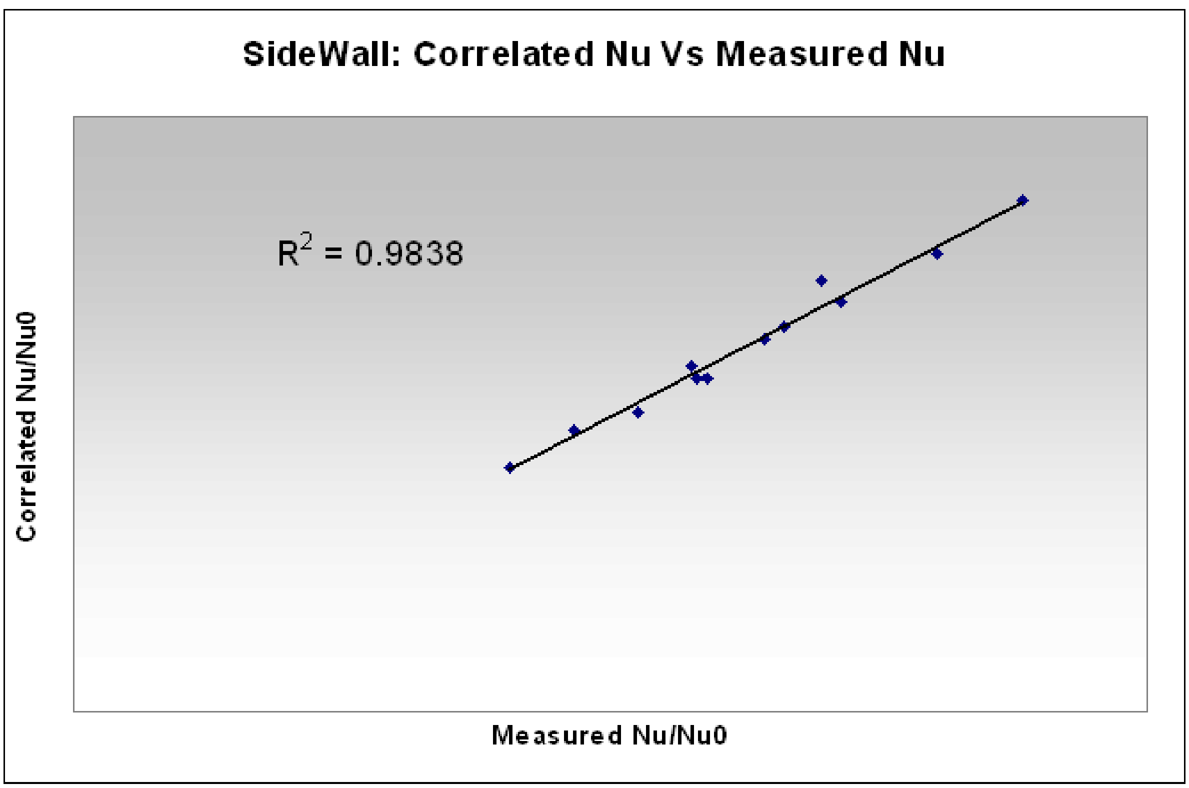
In conclusion the main purpose of this project was to create Heat Transfer and Friction Factor correlations for a Pin Fin array. These correlations might be used in the future to help better model cooling effectiveness of a given Pin Fin array. By being able to better predict the cooling benefit provided by Pin Fins it could be possible to achieve adequate cooling of hot components with slightly less coolant air which could increase the overall engine efficiency. But in addition to Heat Transfer Correlations the project also provided friction factor correlation. This information can be used to minimize pressure loss over the array which also proves to be beneficial.

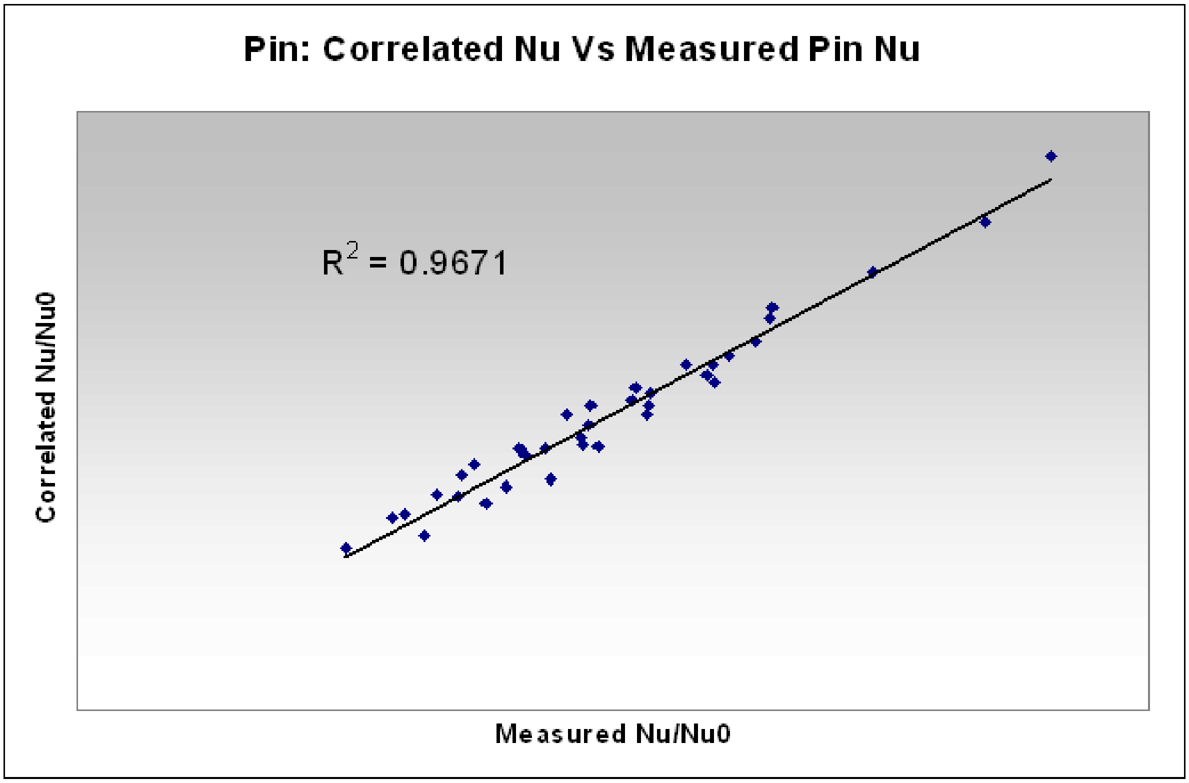
As mentioned before the process was broken down into three major steps. The first is to double check, and where necessary recalculate or in the worst case redo the measured data to ensure that the number of outliers in the data is reduced as much as possible. Next the correlations were created, which were then validated and extrapolated in the last step of the process.

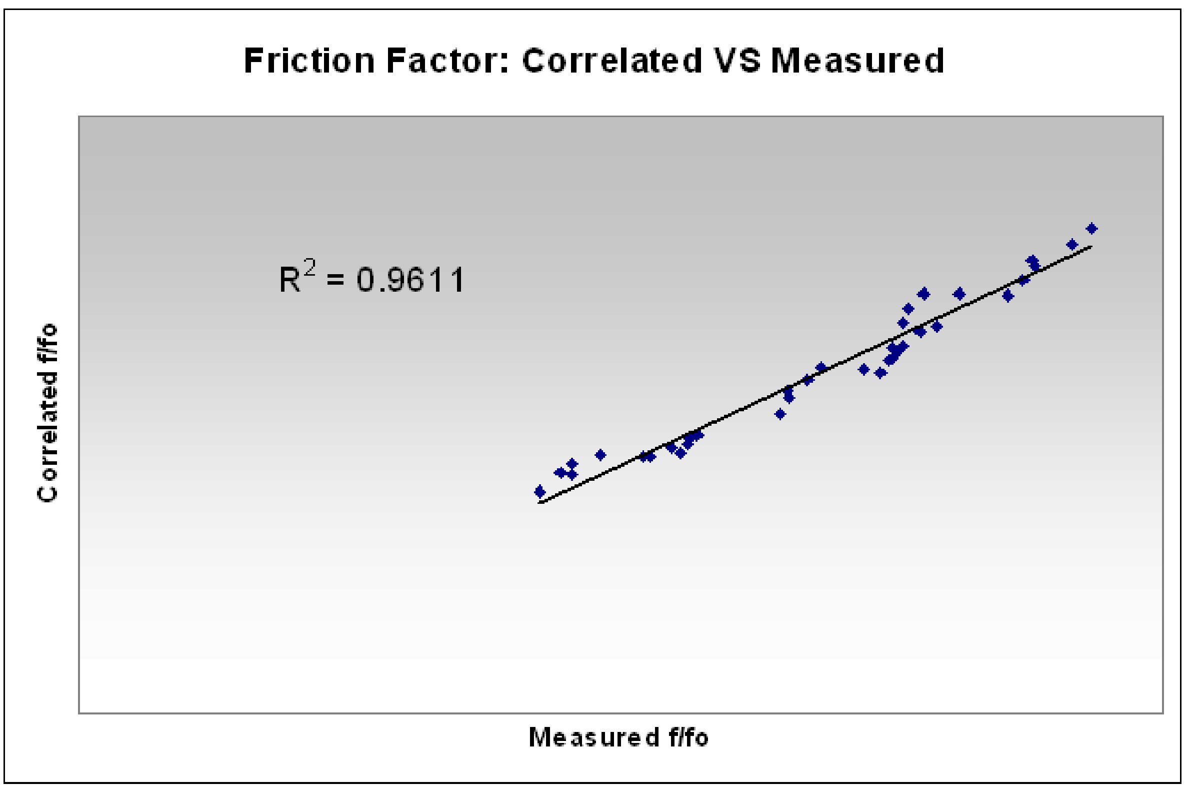
Again, I would like to thank everyone that has made this experience extremely worth while and eye opening. Thank you for all of the support and for giving me this great opportunity.

Appendix


Endwall: Correlated Nu Vs. Measured Nu
R^2 = 0.9447
Correlated Nu/Nu0
Measured Nu/Nu0


SideWall: Correlated Nu Vs Measured Nu
R^2 = 0.9838
Correlated Nu/Nu0
Measured Nu/Nu0


Pin: Correlated Nu Vs Measured Pin Nu
R^2 = 0.9671
Correlated Nu/Nu0
Measured Nu/Nu0


Friction Factor: Correlated VS Measured
R^2 = 0.9611
Correlated f/fo
Measured f/fo

References:

- Chyu, M. K., Hsing, Y.C., Shih, T.I.-P., and Natarajan, V., 1999 "Heat Transfer Contributions of Pins and Endwall in Pin-Fin Arrays: Effects of Thermal Boundary Condition Modeling," ASME Journal of Turbomachinery. Vol. 121, pp. 257-263.

- Vanfossen, G.J., 1982 "Heat Transfer Coefficients for Staggered Arrays of Short Pin Fins," ASME Journal of Engineering for Power, Vol. 104, pp. 268-274.