Silicone Flexible Heaters with Arlon InsilThin™

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Abstract

Silicone flexible heaters consume power during heating and the cost of electricity is a major component of overall operational cost. Global energy demand is pushing the cost of electricity to greater levels year over year. This leads to higher operational costs for silicone flexible heaters. Silicone flexible heaters with improved energy efficiency offer a significant advantage over less efficient legacy products. Arlon InsilThin significantly improves energy efficiency by preventing heat transfer from the silicone flexible heater to the ambient atmosphere. Compared to assemblies with no thermal insulation material, Arlon InsilThin thermal insulation significantly reduces heat loss by approximately 50%. This results in at least 50% less power consumption for a silicone flexible heater in operation. For pipe heating applications, InsilThin in not only 2-3 times thinner than an equivalent silicone foam insulation, but additionally can yield up to 50% power consumption savings compared to silicone flexible heaters assemblies insulated with silicone foam insulation.

Content

1. Introduction

Silicone flexible heaters are widely used in aerospace, semiconductor, telecommunication, food, automotive, medical, and petrochemical industries [1-3]. Silicone flexible heaters maintain heated objects at a certain temperature so that the heated object can function properly. A typical design is shown in **Figure 1**. Silicone rubber is one of the most thermally stable commercially available polymers (up to 220ºC in long term). Electrically resistive wire or foil can be easily bonded and encapsulated by uncured silicone rubber. Fiberglass or other polymeric fabrics make the composite mechanically strong enough for most of applications. The flexibility of the simple composite allows for the design of many complicated heating assemblies.

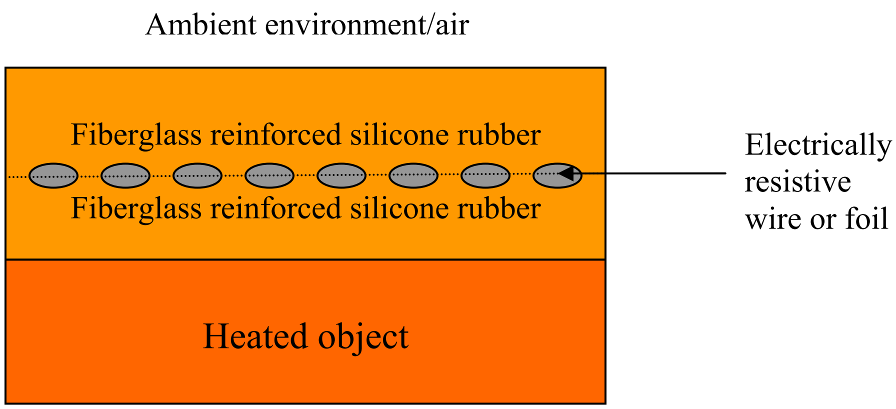

Figure 1: A typical silicone flexible heater design

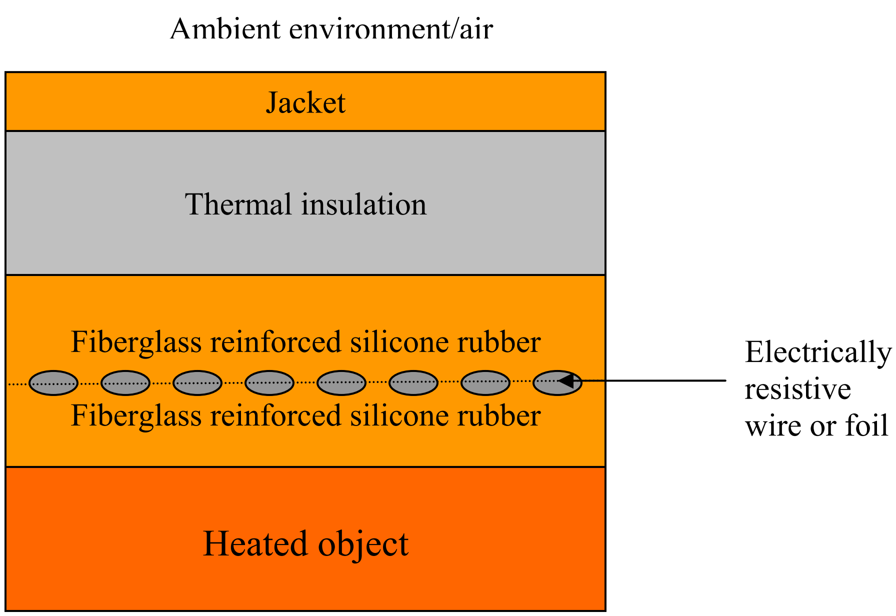

Figure 2: A typical silicone flexible heater design with thermal insulation

Thermally insulative materials are added to a silicone flexible heater for some applications requiring high temperature safety or energy savings purposes. A silicone flexible heater design with thermal insulation material is shown in **Figure 2**.

This paper introduces Arlon InsilThin^{TM}, a silicone-based thermal insulation. It shows dramatically better energy savings compared to a design with no thermal insulation and moderately better energy savings than designs with silicone foam.

2. Heat Loss Factors of a Silicone Flexible Heater

There are three basic ways that heat transfer can take place --- conduction, convection, and thermal radiation. Conduction is used to describe thermal energy transferred within a single body or between two bodies in direct contact with each other. Convection involves transferring energy by physically transporting masses of fluid or gas that contain energy from place to place. Thermal radiation is the electromagnetic radiation energy emitted from the surface of a thermally excited object [4].

In the case of a silicone flexible heater, heat or energy is lost through the surface of the silicone flexible heater or jacket into the ambient air, as shown in **Figure 1 and 2**. Heat transfer processes are mainly conduction, between the heater or jacket and the air, and convection in air, and is described in **Equation 1** [4].

$$Q=hA(T_s-T_f) \qquad \textbf{Equation (1)}$$

Where, Q is heat transfer rate
h is a parameter including heat transfer coefficient, convection coefficient, and film coefficient
T_s is the solid surface temperature
T_f is temperature in the ambient air

Equation (1) defines the factors of heat loss and includes:

- Surface temperature: Higher surface temperature, faster heat transfer rate.
- Surface area: greater surface area, faster heart transfer rate.
- Ambient air temperature: higher ambient temperature, slower heat transfer rate.
- Ambient air circulation rate: this affects parameter h in **Equation (1)**. Faster ambient air circulation rate, faster heat transfer rate.

3. Theoretical heat loss analysis of Arlon InsilThin and silicone foam

No thermal insulation material can effectively insulate a silicone flexible heater adiabatically. When the surface temperature is higher than the ambient temperature, the result is heat loss. Thermal insulation attached to a silicone flexible heater impedes heat from transferring into the ambient environment, and consequently reduces heat loss. Furthermore, at the same surface temperature and heated target object temperature, a silicone flexible heater with thinner thermal insulation, yet equivalent thermal resistance to a thicker insulation design, will consume less energy. Analysis is as follows.

• Flat panel case

Arlon InsilThin with t_1 thickness and silicone foam with t_2 thickness are used in a flat heated object. If we assume that ambient temperature, heated object temperature, heater surface temperature, and heater surface properties are the same, the heat transfer rate per unit area will be the same. We can convert **Equation (1)** into **Equation (2)**:

$$\frac{Q_1}{A_1} = \frac{Q_2}{A_2} \qquad \textbf{Equation (2)}$$

Where, Q is heat transfer rate in Watts
A is the surface area. Calculation is shown in **Figure 3**
"1" designates the Arlon InsilThin design
"2" designates the silicone foam design

$$\frac{Q_1}{WL + 2Wt_1 + 2Lt_1} = \frac{Q_2}{WL + 2Wt_2 + 2Lt_2}$$

Where, W and L are the width and length of heated object respectively
"$WL+2Wt_1+2Lt_1$" or "$WL+2Wt_2+2Lt_2$" is the surface area exposed to ambient environment

$$Q_1 = \frac{WL + 2Wt_1 + 2Lt_1}{WL + 2Wt_2 + 2Lt_2} Q_2 \qquad \textbf{Equation (3)}$$

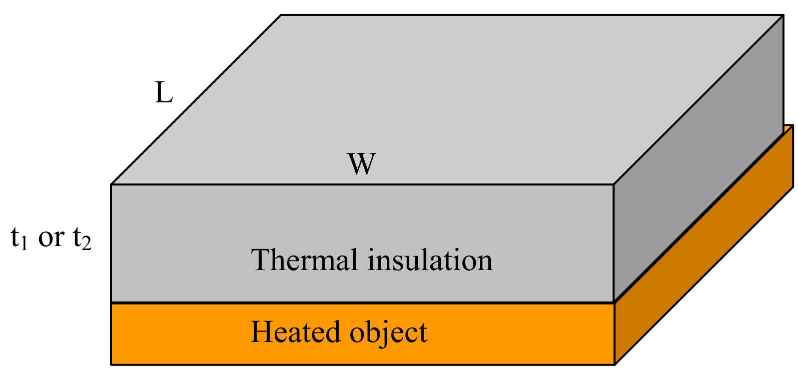

Figure 3: Surface area calculation -- flat panel case

From **Equation (3)** it can easily been seen that if t_1 is less than t_2, Q_1 is less than Q_2. Since Arlon InsilThin is thinner than silicone foam, with the same thermal resistance, at the same surface temperature and heated object temperature [5], it has less heat loss or consumes less energy than silicone foam.

- **Heated pipe case**

Arlon InsilThin with t_1 thickness and silicone foam with t_2 thickness are used at the heated pipe with t_0 diameter. Assumptions are that the ambient temperature, hot pipe temperature, surface temperature, and surface properties are equivalent, than the heat transfer rate per unit area will be the same, as described in **Equation (2)**. The surface areas calculation is shown in **Figure (4)**.

$$\frac{Q_1}{\pi(t_0 + 2t_1)L} = \frac{Q_2}{\pi(t_0 + 2t_2)L}$$

Where, L is the length of heated pipe
$\pi(t_0+2t_1)$ or $\pi(t_0+2t_2)$ is the circumference of the insulated heated pipe

$$Q_1 = \frac{t_0 + 2t_1}{t_0 + 2t_2} Q_2 \qquad \textbf{Equation (4)}$$

From **Equation (4)** it is easily seen that if t_1 is less than t_2, Q_1 is less than Q_2. Since Arlon InsilThin is thinner with similar thermal resistance than silicone foam at the same outside surface temperature and heated pipe temperature [5], it has less heat loss or consumes less energy than silicone foam.

From **Equation (4)** it can easily be seen that the power consumption ratio, (Q_1/Q_2), between InsilThin and silicone foam also depends on the diameter of hot pipe (t_0). The smaller t_0, the greater the difference between Q_1 and Q_2, and when t_0 approaches zero, Q_1/Q_2 reaches a minimum value. Since InsilThin is 2-3 times thinner than silicone foam with the same thermal resistance, InsilThin insulated flexible heaters use up to 50% less heat loss and energy usage than silicone foam insulated assemblies in the heated pipe design.

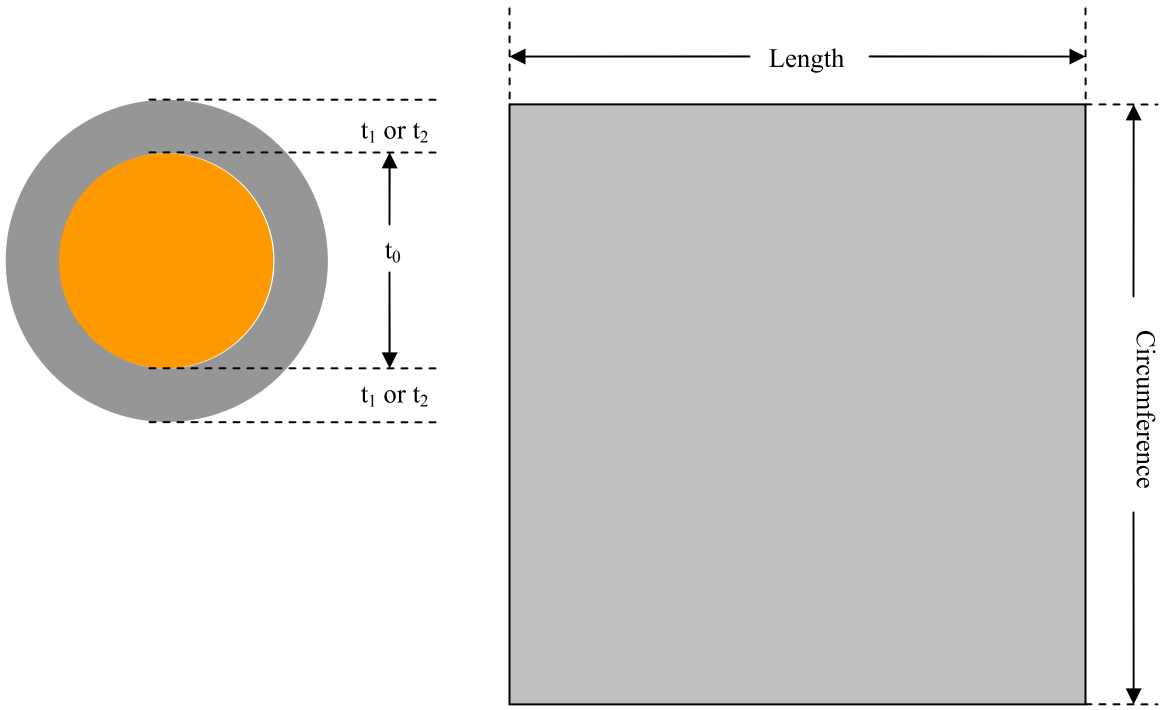

Figure 4 Surface area calculation for the heated pipe design case

4. Experimental

4.1 Materials

Arlon InsilThin (0.084" thick), 0.25" thick silicone foam, 0.50" thick silicone foam

4.2 Instruments

The experimental set up is shown in **Figure 5**. A glass tube is filled with silicone fluid. Thermal couple T_1 is connected to the temperature controller of an Omega silicone flexible heater. The power consumption of silicone flexible heater is recorded by a power meter (METEX M-3860M) and its software (METEX DMM Multiview). Thermal couples T_2, T_3, T_4, T_5, and T_6 are connected to temperature recorder-Plcolog.

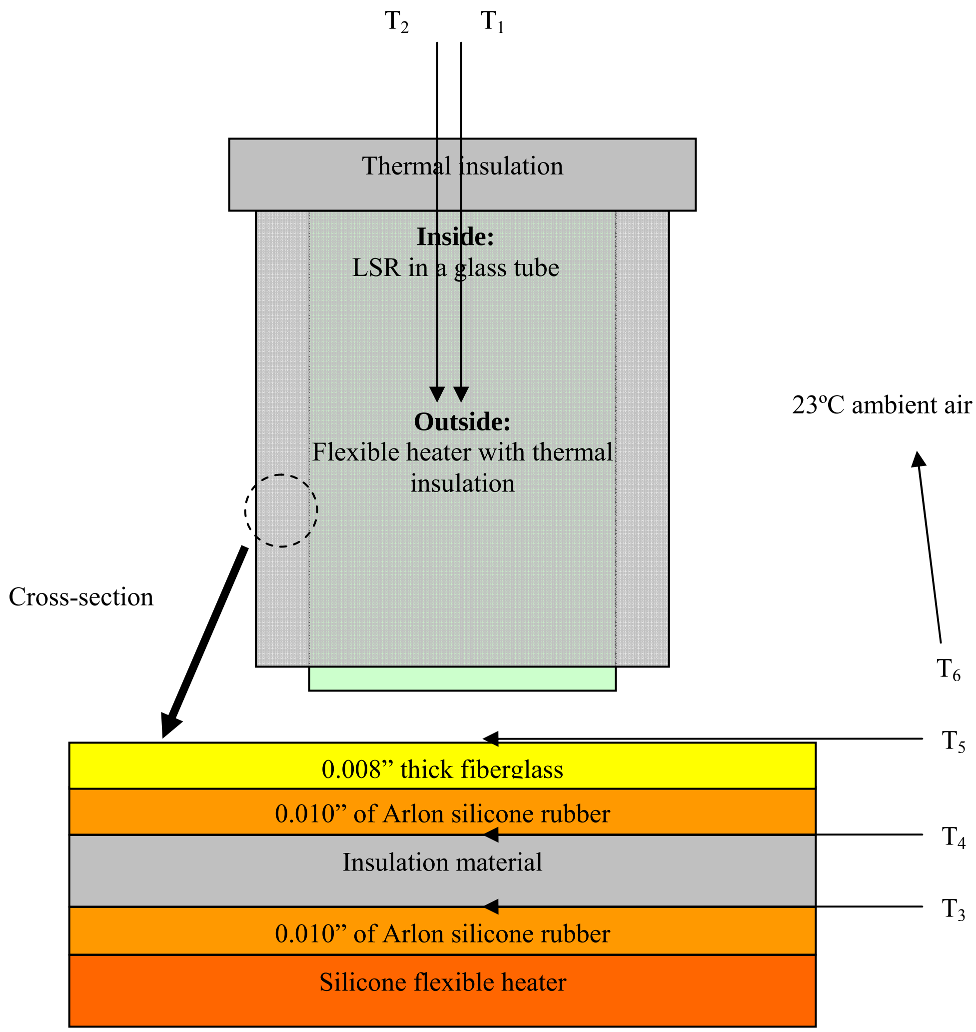

Figure 5: Energy efficiency experiment

4.3 Procedure

Air temperature in the conditioned test room is controlled at 23°C ± 1. After all instruments are set up, a test temperature is chosen for the temperature controller. The METEX M-3860M, METEX DMM Multiview, and Plcolog are powered on to start recording power and temperatures, as shown in **Figures 6 and 7**. Experimental results are recorded after ~8 heating cycles. Average power and temperatures are calculated by using the data of ~5 heating cycles at steady state (after ~1000sec).

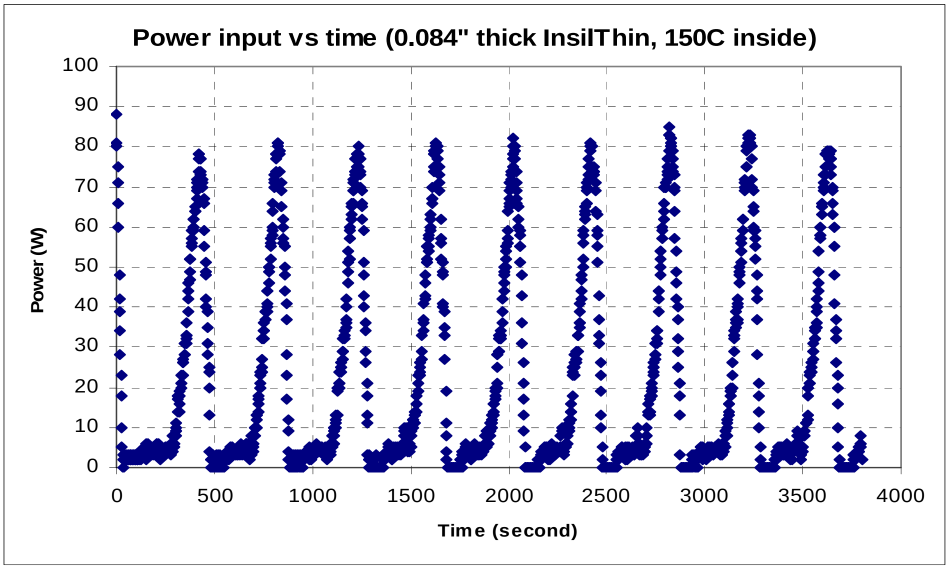

Figure 6: Power consumption example recorded by METEX M-3860M and METEX DMM Multiview

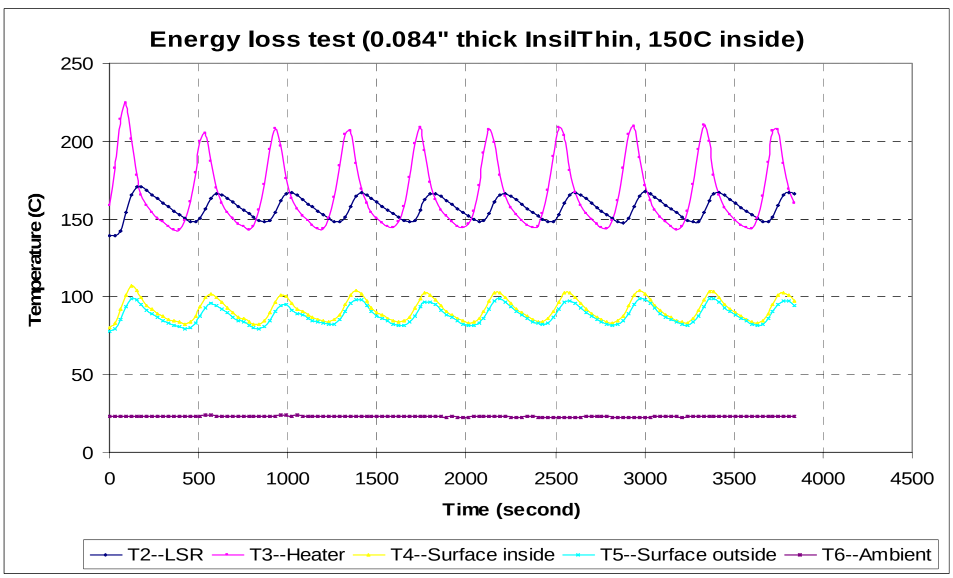

Figure 7: Example of temperatures recorded by Plcolog

5. Results and Discussion

4.1 Arlon InsilThin versus no thermal insulation

A liquid silicone filled glass tube (3.5" diameter) heated by an Omega silicone flexible heater (SRFG-511/5 model: 5"*11", 300W) is used in this experiment. A silicone flexible heater insulated with Arlon InsilThin is compared to a silicone flexible heater with no thermal insulation, as shown in **Figure 8**. The silicone flexible heater with one layer of InsilThin (0.084") consumes ~50% less power than the silicone flexible heater without thermal insulation, to maintain the same liquid silicone temperature inside of the glass tube. The silicone flexible heater with two layers of InsilThin (0.168") consumes ~60% power than the silicone flexible heater without thermal insulation, to maintain the same liquid silicone temperature inside the glass tube.

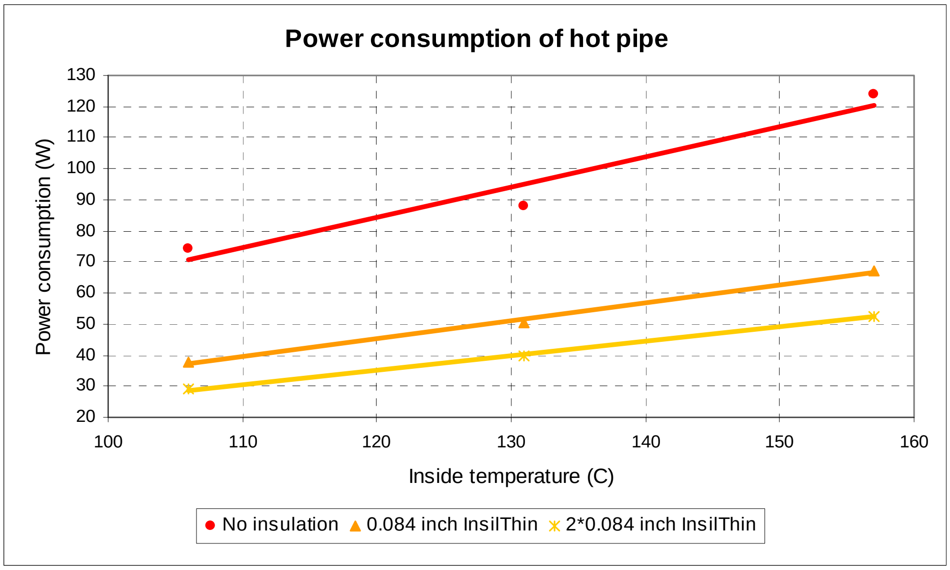

Figure 8: Power consumption comparison between InsilThin and no thermal insulation

4.2 Arlon InsilThin versus silicone foam insulation

A one inch diameter glass tube filled with liquid silicone heated by an Omega silicone flexible heater (SRFG-306/5 model: 3"*6", 100W) is used in this experiment. The silicone flexible heater insulated with Arlon InsilThin is compared to a silicone flexible heater insulated with silicone foam. (**See Figure 9 and Figure 10)** At the same liquid silicone temperature inside the glass tube, the silicone flexible heater with one layer of InsilThin (0.084") has almost the same outside surface temperature as the silicone flexible heater insulated with a 0.25" thick silicone foam. The silicone flexible heater with two layers of InsilThin (0.168" thickness) has almost the same outside surface temperature as the silicone flexible heater insulated with a 0.50" of silicone foam. This means that both insulation systems have similar performance in terms of reducing assembly outside surface temperature, when safety is a specified concern.

However, the silicone flexible heater insulated with one layer of InsilThin (0.084") consumes ~20% less power than a silicone flexible heater insulated with a 0.25" thick silicone foam required to maintain the same liquid silicone temperature inside the glass tube. The silicone flexible heater with two layers of InsilThin (0.168" thickness) also consumes ~20% less power than a 0.5" thick silicone foam insulated flexible heater, to maintain the same liquid silicone temperature inside of glass tube.

The test result is close to the theoretical calculation: (23% (Equation 4: Q_1=0.77Q_2) for 0.084" thick InsilThin compared to 0.25" thick silicone foam and 34% (Equation 4: Q_1=0.66Q_2) for 2*0.084" thick InsilThin versus a 0.5" thick silicone foam as seen in **Equation (4).**

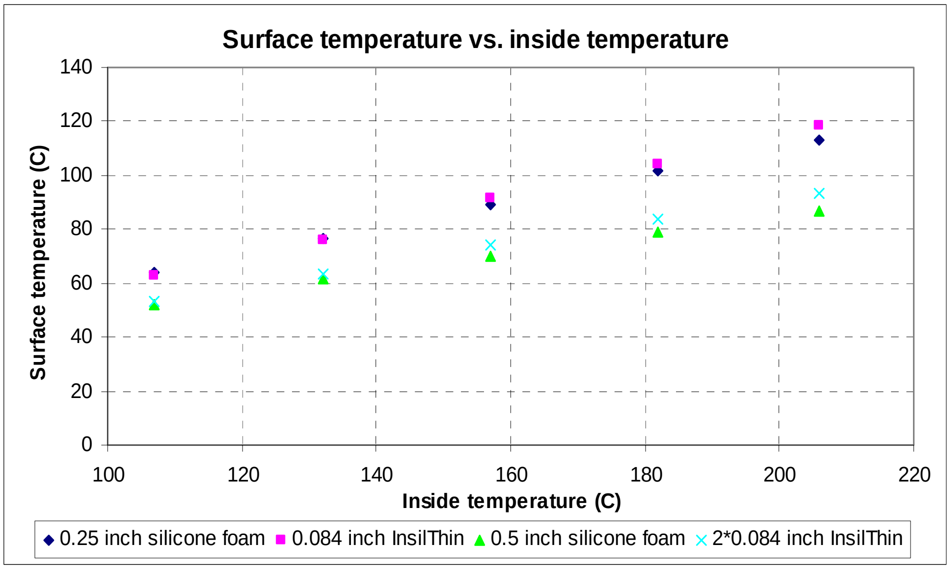

Figure 9: Surface temperature comparison between a silicone flexible heater assemblies insulated with InsilThin or silicone foam

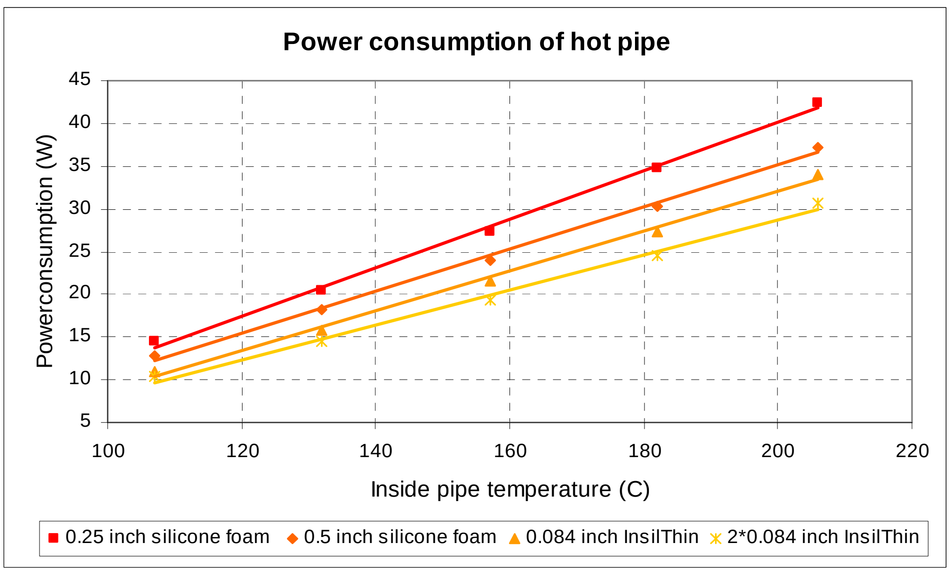

Figure 10: Power consumption comparison of silicone flexible heater assemblies insulated with InsilThin or silicone foam.

6. Energy savings by using Arlon InsilThin

The price of electricity is likely to continue to steadily increase in the foreseeable future. Manufacturing facilities that utilize a significant amount of electricity to generate heat to maintain specified operating temperatures for piping assemblies and equipment should greatly benefit from the use of insulated flexible heater assemblies. A good example of the annual cost savings, through the use of InsilThin in flexible heating assemblies, can be seen by reviewing the experimental results in section 4.1 from a simple financial perspective. If the actual experimental heating assembly was utilized in an industrial setting to maintain a fluid temperature of 150°C under the following conditions:

Operational Time = 16 hours a day for 250 days a hear
Fluid Temperature Operation = 150°C
Flexible Heater Power Consumption (No insulation): Figure 8 = 112 Watts
Flexible Heater Power Consumption (Insulated with InsilThin): Figure 8 = 62 Watts
Silicone Flexible Heater Dimensions = 5" x 11"
Electricity Price= $0.10 kWh

Then the annual energy costs for operating the system without insulation are:

16 hours/day x 250 days/year x 0.112 kW x $0.10/kWh = $44.8/year

And insulated with InsilThin are:

16 hours/day x 250 days/year x 0.062 kW x $0.10/kWh = $24.8/year

For an annual operational cost savings of $20. The average incremental cost of insulating a flexible heating assembly of this size with InsilThin pales in comparison to the annual cost savings that may be achieved. In a facility with a large numbers of silicone flexible heating units utilized on equipment, the energy cost savings factor should be thoroughly considered when choosing a flexible heating solution.

7. Summary

Power consumption of a silicone flexible heater depends on the surface temperature, surface area, ambient temperature, and ambient air circulation rate. The experimental results indicate that a silicone flexible heater with Arlon InsilThin consumes approximately 50% less power than an assembly without thermal insulation. Additionally, a silicone flexible heater insulated with Arlon InsilThin is 2-3 times thinner and consumes up to 50% less power than a silicone flexible heater insulated with silicone foam for pipe heating applications.

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