CPSC/LS/TR—04/001

Fire Indicators Project Report

April 2004

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Background

Underwriters Laboratories' (UL's) voluntary standards use a variety of fire indicators to evaluate the fire safety of products. These fire indicators are typically intended to represent some type of household combustible. If an indicator that is subjected to heating from a consumer product under certain conditions performs in a defined way, the product is deemed to be a fire hazard. For example, UL 2021, *Fixed and Location-Dedicated Electric Room Heaters*, states that "a heater, loosely covered with a single layer of terry cloth, shall not cause the cloth to glow or flame." (42.7.1). This evaluation method provides for only a pass or fail criterion.

U.S. Consumer Product Safety Commission (CPSC) staff believes a more useful measure of the heating performance of a product would be a measurement of the heat flux emitted by the product. This numerical measure would allow for a performance criterion to be set, just as with a fire indicator evaluation, but would also provide a relative measure of performance. Measuring the heat flux emitted with calibrated sensors is also a more repeatable test than using an artifact indicator. For example, the terry cloth specified in UL 2021 may vary somewhat from manufacturer to manufacturer, so that the fire safety conclusions about a heater may be vastly different if even slightly different indicators are used.

During FY02, the CPSC staff contracted with the University of Maryland (UM) to determine the critical heat flux necessary to ignite ten different materials: five household materials and five standard fire indicators. An additional component of the FY02 project involved CPSC staff testing of a small set of heat-producing consumer products to determine the heat flux emitted by them. The FY02 project report can be found at http://www.cpsc.gov/LIBRARY/FOIA/FOIA03/os/fip2003.pdf.

The FY03 test program, conducted by CPSC staff, built on the FY02 work done by UM. The FY02 test program evaluated the performance of single layers of materials under different heat flux conditions and configurations. The FY03 program included similar testing, but with multiple layers of materials and with materials backed by a non-combustible substrate, based on specific recommendations in the UM report.

Objective

The long-term objective of this project is to examine the feasibility of considering quantitiative heat flux requirements in place of artifact fire indicator requirements in appropriate UL standards. Quantitative measurements would have the advantage of giving relative results as opposed to just being a pass or fail threshold as in current standards. Also, the variability of the indicator material would no longer be a factor. The indicators could still be used for graphic demonstrations of the heating potential of products, but would no longer carry the weight of a performance test. In some cases, particularly where the indicator is used to detect and demonstrate the hazard of arcing instead of heating, the quantitative heat flux approach may not be appropriate. The decision to use heat flux measurements, fire indicators, or a combination of methods would depend on the type of product and the nature of the potential ignition source that is being addressed by the test specified.

Another objective of this project is to evaluate the effects of multiple layers of materials and materials with a non-combustible substrate backing on the critical heat flux. Some UL tests specify multiple layers of material to better simulate the household materials they are chosen to represent.

Samples

The test protocol in the FY02 testing included ten materials. In FY03, because of the increased scope of the test work, the list was reduced to six materials. Five of the FY03 test materials were chosen from among the materials previously tested; bed sheets were added as a new test material because of their potential to be the first item ignited by a space heater, for example. Where applicable, the test materials used complied with UL standard specifications. The newsprint used was taken from the Washington Post Classifieds because they are black and white and have somewhat consistent inking patterns. The paper towels were all white, two-ply, and from a national brand. The cotton bed sheets met the specifications used in other CPSC testing (16 CFR Part 1632, *Standard for the Flammability of Mattresses and Mattress Pads*). All of the materials are listed in Table 1.

Table 1. Sample materials for both FY02 and FY03 test programs.

FY02	FY03
Tissue paper	--
Cheesecloth	Cheesecloth
Paper towel	Paper towel
Newsprint	Newsprint
Surgical cotton	--
Cotton duck	Cotton duck
Blanket	--
Upholstery fabric	--
Terry cloth (beige)	--
Terry cloth (white)	Terry cloth (white)
--	Bed Sheets

Single layer samples of each material tested were cut and weighed and their surface densities calculated. A surface density is a two dimensional measurement of density, represented as a mass per unit area. This reflects the phenomenon that even for a solid block of fuel, only a thin layer at the surface is actively involved in the combustion process when ignited. The representative surface densities are shown below in Table 2.

Table 2. Representative surface densities of test materials.

Material	Surface Density (kg/m^2)
Cheesecloth	0.038
Paper towel	0.041
Newsprint	0.049
Bed sheets	0.124
Cotton duck	0.247
Terry cloth (white)	0.373

These results are comparable to those measured in the FY02 testing with the exception of the bed sheets and the cotton duck material. Bed sheets were not previously tested and identical cotton duck was not available. The cotton duck purchased for this testing was advertised with comparable specifications to comply with the requirements of UL 2021, *Fixed and Location-Dedicated Electric Room Heaters* (0.273 kg/m^2). However, the product that was shipped did not meet that specification. The company (which specializes in test fabrics) claims the proper product was shipped and was not alarmed by the almost ten percent discrepancy. This discrepancy further illustrates the need for more explicit requirements for fire indicator materials.

Test Apparatus

Two standard bench scale test devices were used to determine ignition properties of materials. They were an oxygen consumption calorimeter (cone calorimeter) and a lateral ignition and flame spread test (LIFT) apparatus. Both devices used by the CPSC staff are located at the University of Maryland's Pyrometrics Laboratory and were the same devices used in the FY02 UM testing. Both were used in accordance with their applicable ASTM standards: E1354-02, *Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter*, and E1321-97a, *Standard Test Method for Determining Material Ignition and Flame Spread Properties*. The cone calorimeter test uses an electric heating element to heat a horizontally mounted sample while the LIFT device uses a gas-fired radiant panel to heat a vertically oriented sample.

Test Results

Each sample was tested over a range of heat flux conditions and the time to glowing and/or flaming ignition was measured. If no ignition occurred within 20 minutes, the test was stopped. Ideally, data points were collected at heat fluxes both above and below the critical heat flux needed to cause ignition so as to narrow in on the critical heat flux empirically. However, because of device limitations, this was not always possible. In particular, the LIFT apparatus became unstable or even inoperable at lower heat fluxes (below approximately 15-17 kW/m^2). For data series where data points were not attained below the critical heat flux required for ignition, alternate analyses can still give meaningful results.

Test results are shown in Figures 1-12. Each graph shows the results for all six configurations tested (single and multiple layers, with and without a substrate) of a single material with a specific apparatus. The figures show the time to ignition as a function of the incident heat flux. Note that 1200 seconds is equal to 20 minutes, which was the cutoff point for all tests. In some cases, ignition may have occurred beyond the 20-minute interval if the test had been allowed to proceed. In these plots, the ideal curve would have a sharp, asymptotic shape near the critical heat flux. Because of the 20-minute cutoff, there is a level plateau at 1200 seconds. In a few cases, there was an anomaly in the data that resulted in an ignition measurement at a lower flux than a non-ignition measurement. The same phenomenon was seen in the FY02 testing and cannot be easily explained.

In seeking to establish a correlation basis, the results are also plotted as a function of the inverse of the ignition time (t_{ig}^{-1}) in Figures 13-24 and as a function of the inverse of the square root of the ignition time ($t_{ig}^{-1/2}$) in Figures 25-36. These formats relate to the "thermally thin" and "thermally thick" analyses presented in the next section. One advantage of presenting the data in this way is to minimize the graphical impact of the 20-minute cutoff point. Inverting the time to ignition causes those non-ignition data points to approach zero rather than infinity, or in this case the artificial 20-minute cutoff point.

Data Analysis

All test results from both devices and in all configurations were analyzed using the thermally thin and thermally thick theories for ignition. The thermally thin theory assumes that a material is thin enough to have a uniform temperature through its thickness. The surface receiving the incident heat flux and the back surface have a negligible temperature difference. The thermally thick theory assumes that a material does have temperature gradients through it. Specifically, it assumes that the back surface does not experience any of the heating of the exposed front surface or the subsequent heat transfer into the material. For both ignition theories, it is assumed that the materials have constant thermal properties and that the materials are static until the ignition temperature (T_{ig}) is reached.

Thermally Thin Analysis

Reiterating the theory from the University of Maryland report (Pages A-4 – A-5 of the FY02 Fire Indicators Project Report):

> For thermally thin materials, the energy per unit area that must be absorbed to raise the material to its effective ignition temperature is
>
> $$q_{ig} = \rho\delta c(T_{ig} - T_o) \quad (1)$$
>
> where $\rho\delta$ represents the surface density of the material (kg/m^2) given in Table 2, c is the specific heat of the material (kJ/kg•K) and ($T_{ig} - T_o$) is the temperature rise (K) needed to cause ignition. For a constant net rate of energy absorption, $q^{\cdot}_{net}$, the time to ignition can be represented as:

$$q_{ig} = \int_0^{t_{ig}} q^{\cdot}_{net}\, dt = q^{\cdot}_{net}\, t_{ig} \quad \text{or} \quad t_{ig} = q_{ig} / q^{\cdot}_{net} \tag{2}$$

Due to convective and radiative heat losses from the surfaces of a material as it heats up, the net rate of energy absorption will only be some fraction of the incident heat flux:

$$q^{\cdot}_{net} = \chi_{net}\, q^{\cdot}_{inc} \tag{3}$$

where χ_{net} represents the absorbed fraction of the incident heat flux. While the value of χ_{net} is expected to vary as the material heats up under the incident heat flux, as a first approximation it is treated as constant. In this case, the time to ignition can be determined in terms of the incident heat flux, rather than the net heat flux, as:

$$t_{ig} = q_{ig} / \chi_{net}\, q^{\cdot}_{inc} \tag{4}$$

Note the inverse relationship between the time to ignition and the incident heat flux, which suggests that a plot of t_{ig}^{-1} versus $q^{\cdot}_{inc}$ should yield a linear relationship with a slope of χ_{net}/q_{ig}. Alternatively, the product of the ignition time by the incident heat flux, i.e., $t_{ig} q^{\cdot}_{inc} = q_{inc,ig} = q_{ig} / \chi_{net}$, represents the total incident heat load for ignition. To the extent that the absorbed fraction of incident heat flux is a constant and the ignition temperature is independent of the heating rate, the total incident heat load for ignition should also be constant. To test this hypothesis, the total incident heat load for ignition was determined for all the samples that ignited.

Figures 37 and 38 plot the total incident heat load for ignition for each apparatus. The curvature and scatter in these plots are similar to that of the FY02 testing and likewise indicate that the thermally thin hypothesis is not correct.

Thermally Thick Analysis

Excerpting the theoretical explanation from the FY02 UM report (Pages A-5 – A-6):

For thermally thick materials, the time to ignition is related to a constant net heat flux at the exposed surface as:

$$t_{ig} = (\pi/4)\, k\rho c\, [(T_{ig} - T_o)/(q^{\cdot}_{net})]^2 \tag{5}$$

As for the thermally thin case, the net rate of energy absorption will only be some fraction of the incident heat flux due to convective and radiative heat losses from the exposed surface of the material as it heats up:

$$q^{\cdot}_{net} = \chi_{net} q^{\cdot}_{inc} \tag{3}$$

where χ_{net} represents the absorbed fraction of the incident heat flux. While the value of χ_{net} is expected to vary as the material heats up under the incident heat flux, as a first approximation it is treated as constant. With this assumption, the ignition time can be related to the incident heat flux as:

$$t_{ig} = (\pi/4)\, k\rho c\, [(T_{ig} - T_o)/(\chi_{net}\, q^{\cdot}_{inc})]^2 \tag{6}$$

This suggests that a plot of $t_{ig}^{-1/2}$ versus the incident heat flux should yield a linear relationship with a slope of $\frac{2\chi_{net}}{(T_{ig}-T_o)\sqrt{\pi k \rho c}}$. Alternatively, the product of the ignition time by the square of the incident heat flux should be a constant if the material thermal inertia and ignition temperature are constant, the net heat flux fraction is constant and the thermally thick theory of ignition is valid. This product is:

$$t_{ig}\, \dot{q}_{inc}^{2} = (\pi/4)\, k\rho c\, [(T_{ig} - T_o)/(\chi_{net})]^2 = \text{TERP} \qquad (7)$$

where TERP stands for the thermal effective response parameter.

The TERP values are plotted in Figures 39 and 40. As before, the scatter in these plots seems to indicate that the assumptions concerning the stability of the material thermal inertia and ignition temperature are not correct. Though obscured somewhat by the scatter in the plots, the trend seen in the FY02 testing, that the TERP increases as heat flux approaches the critical heat flux, is still apparent in the FY03 data.

Discussion

The main objective of this test program was to supplement the test work done at the University of Maryland in FY02 by including multiple layer configurations for the materials tested. In particular, since it was observed in the FY02 testing that the lightest materials seemed to disintegrate before they could ignite, it was theorized that increasing the mass of the samples by adding layers might provide more consistent results. Additionally, since some UL standards specify using multiple layers of fire indicator materials, this test program was intended to gain a better understanding of the performance of multiple layers of material under radiant heating conditions.

Device Comparison

Generally, the cone calorimeter yielded marginally lower critical heat fluxes for ignition than did the LIFT apparatus. This is a reversal of the FY02 results where only one layer of material was tested. In large part, this is believed to be because of the frame used to hold the sample in the LIFT device.

In the FY02 testing, a square frame was used to hold the sample. Because of the configuration of the LIFT device, this meant that approximately 5 ½ inches of the six-inch piece of material being tested was suspended freely, while the last half-inch was supported from behind with a marinite frame. Effectively, this meant that a small portion of the sample was tested under different conditions than the rest of it. The effect of the frame was noted in the FY02 report. It was observed that the area supported by the marinite frame was very often where ignition first occurred.

To eliminate this effect, a different test frame was used in the FY03 testing. A "C"-shaped frame was constructed to allow the entire six-inch sample to be freely suspended without a substrate backing behind any portion of it. Consequently, there was no observed tendency for ignition to occur at any particular site on the sample.

As will be discussed in the section on substrate effects, having a substrate behind even a small portion of the sample could have noticeably lowered the critical heat flux and resulted in the noted discrepancy between the cone calorimeter and LIFT results in the FY02 results.

The remaining differences in the data are the result of other factors. The most likely factors are inherent to the test apparatus used. The cone calorimeter subjects test materials oriented horizontally to radiant heat from an electric coil heater. Material tested with the LIFT apparatus is oriented vertically and heated with a gas-fired radiant panel. The difference in orientation affects the behavior of the pyrolyzates (volatile gases given off by solids at high temperatures). With the cone calorimeter, the pyrolyzates rise off the surface uniformly; with the LIFT, the concentration of pyrolyzates rises closer to the top edge of the sample and continues to rise beyond the top edge due to buoyancy effects.

Layer Effects
Generally, multiple layer test configurations yielded lower critical heat fluxes than single layer configurations. This was particularly true with the lightest materials since they were often observed to pyrolyze without igniting with fewer layers present. This observation was noted during the FY02 testing and was also seen in the latest round of tests. However, adding layers of material seemed to stabilize these light materials (i.e. cheesecloth, paper towel, and newsprint) and also lowered the measured critical heat flux, dramatically in some cases. For example, one layer of cheesecloth required more than 38.7 kW/m^2 to ignite with the cone calorimeter, while 10 layers needed less than 17.5 kW/m^2. Similarly, the critical flux required to ignite newsprint with the cone calorimeter was greater than 24.6 kw/m^2 for one layer, but only 13.4 kW/m^2 for 10 layers.

Even for the heavier materials, the addition of multiple layers of material lowered the critical heat flux required for ignition. Bed sheets, for example, were ignited at 18.6 kW/m^2 for one layer, 10.0 kW/m^2 for three and five layers, and less than 8.4 kW/m^2 for ten layers in the cone calorimeter. Intuitively, there is a limit to how many layers can be added to increase this effect: the difference in performance between one and three layers is expected to be greater than the difference between 30 and 33 layers. This test program was limited to testing a finite number of configurations; finding the limiting factor was not a goal.

The reason for the lowered critical heat flux for ignition may be the decreased heat transfer from the top layer due to the additional layers behind it. Since some of the heat that escapes from the back surface of the top layer is re-radiated back to the top layer, the concentration of pyrolyzates given off by the top layer is increased. At some point, the gases given off behind the top layer increase enough to tear the top layer and the edge of the torn material begins to glow. This phenomenon was seen repeatedly when testing multiple layer samples. Furthermore, the glowing edge of the top layer often seemed to act as a pilot light for the remaining material. When the concentration of flammable gases reached an ignitable level, that glowing edge became the ignition source for flaming combustion.

Substrate Effects
In some ways, the substrate can be seen as additional layers behind the top layer: it insulates the top layer and inhibits heat from being given off the back side of the material. On the other hand, unlike multiple layers of material, the substrate does not contribute to the fuel load. The test results reflect this in broad terms. Tests with one layer of material with a substrate usually ignited at lower heat fluxes than one layer without a substrate. However, they still did not perform as if there was an infinite thickness of material present. The material performed qualitatively the same as if there was no backing; it was still prone to pyrolyzing without ignition. When five layers were tested with a substrate, they performed more like the other multiple layer tests. There seemed to be enough material present to reach ignition sooner than when just one layer of material was backed with the substrate. At some point, the performance of multiple layers with and without a substrate would be the same. As before, determining the number of layers required to reach that threshold was not a goal of this program. Demonstrating the effects on performance of the different scenarios was the primary goal.

Ignition Theories
As was seen in the FY02 testing, the thermally thin and thermally thick theories for ignition do not appear to be valid across all heat fluxes in the range tested. They appeared to break down close to the critical heat flux for ignition.

Some of this break down in the theory can be attributed to the assumptions made when invoking the theory: that material properties are constant and that the materials do not react until the ignition temperature is reached. However, the theories seem to hold at supercritical heat fluxes. The figures plotting the data using a thermally thin analysis appear linear in the supercritical range in most cases. Fitting a trend line to these data was often possible and provides insight into a possible projected critical heat flux. This technique was especially useful when examining the LIFT data since the apparatus often did not allow for measurements at or below the critical heat flux.

Summary

The most consistent results were obtained with the heavier materials, particularly the cotton duck. The bed sheets yielded the lowest critical heat flux of all the materials tested: less than 8.4 kW/m^2 for ten layers in the cone calorimeter. Collectively, the bed sheets, cotton duck and terry cloth yielded critical fluxes in the approximately 8-12 kW/m^2 range for three or more layers. The three lightest materials, the cheesecloth, paper towels and newsprint, had critical heat fluxes between 11 and 25 kW/m^2 for the multiple layer tests.

The appliance testing in the FY02 report was not repeated here. However, it is clear that of the appliances selected and tested during that project, only one of the two properly operating radiant heaters would have sufficient energy to ignite any of the materials tested in either phase of the project. That heater generated a maximum heat flux of 21.5 kW/m^2, which could ignite any of the materials in this project if multiple layers were present. A second heater produced a maximum heat flux of 5.9 kW/m^2. The minimum observed heat flux that caused ignition in this test program was 8.4 kW/m^2 for ten layers of bed sheets. Also, there could be other heaters or other products that generate a heat flux between 5.9 and 21.5 kW/m^2 that would ignite some or all of these indicators in multi-layer configurations.

It should also be noted that the material that registered the lowest heat flux to cause ignition was not a standard fire indicator. It was bed sheet material that was selected for this testing to represent other household combustibles and a possible first item ignited. This implies that the fire indicator requirements in UL standards may need to be reconsidered, as suggested by the anecdotal data that fires are still being caused by listed and properly maintained products.

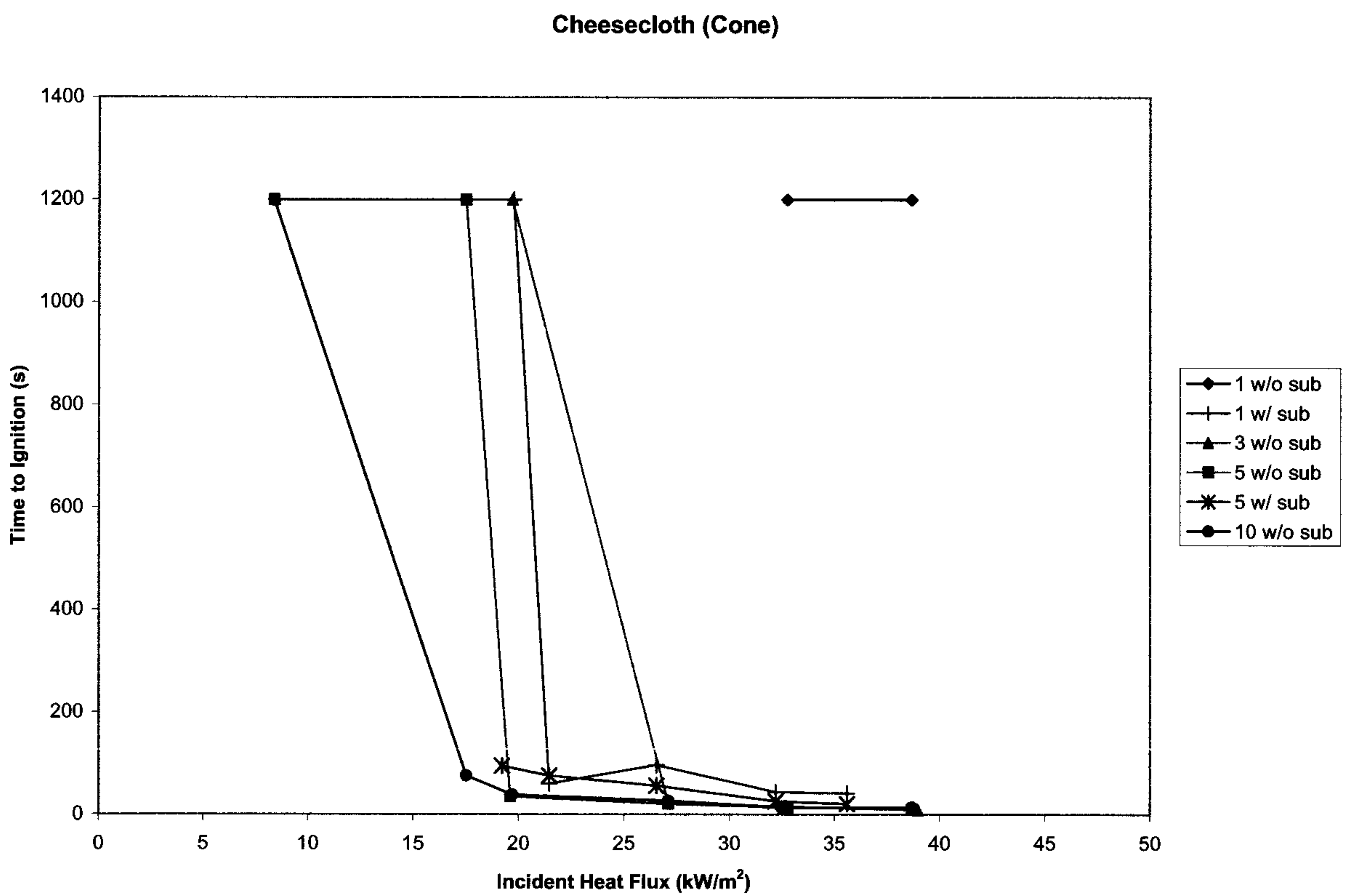
Conclusion and Recommendations

The testing in both FY02 and FY03 involved a sampling of several fire indicators and household combustibles. This testing begins to give a quantitative understanding of the behavior of these materials under radiant heating conditions. To date, it appears that some of the materials are better suited to be used as standard fire indicators than others, either because of their consistent performance or low critical heat flux values. In particular, of the materials tested, the cotton duck and bed sheets resulted in the most consistent results and lowest critical heat fluxes.

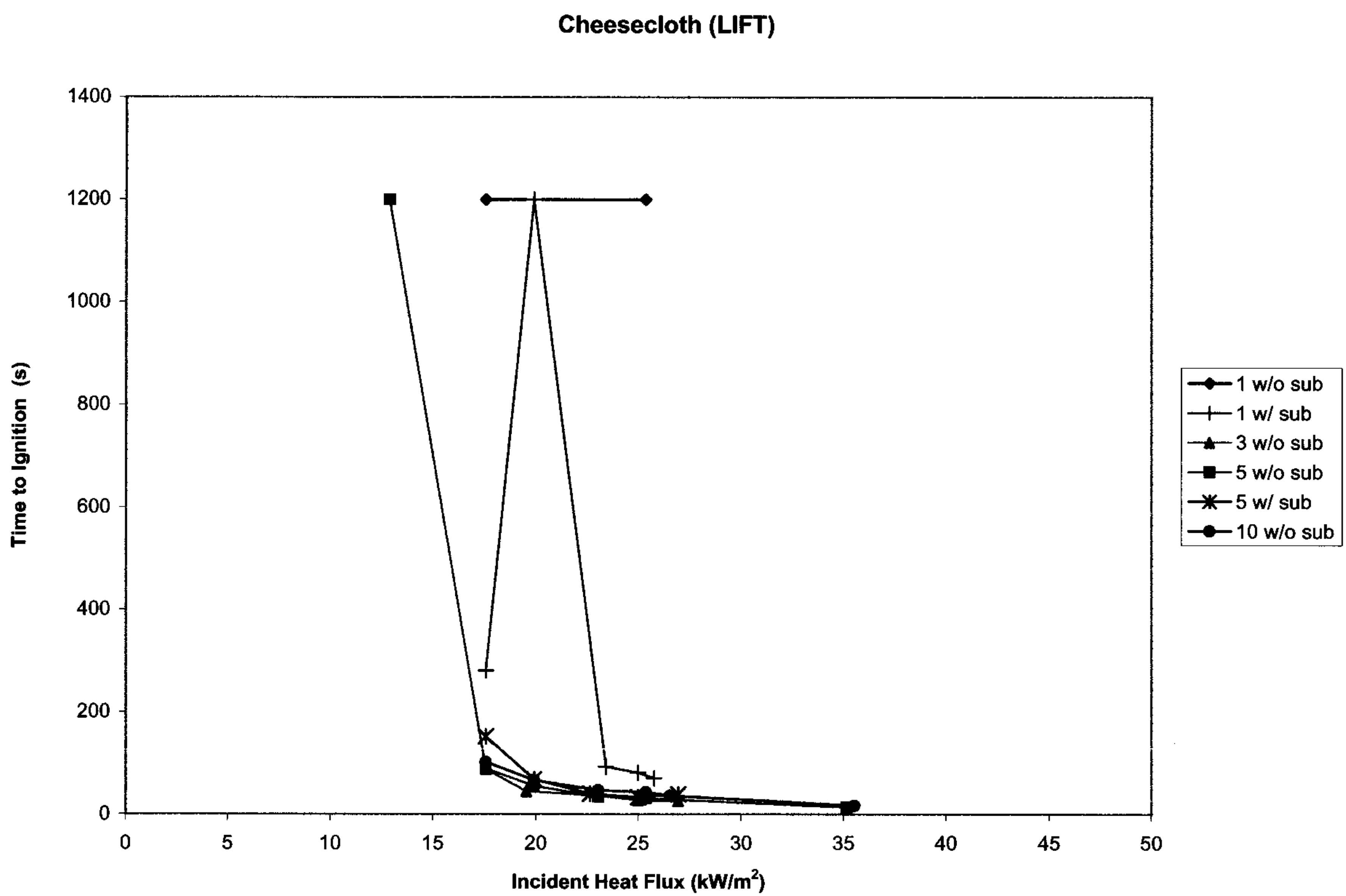
The testing has also demonstrated that standard specifications for a fire indicator do not necessarily guarantee the intended results. The almost ten percent difference in the material density of the two cotton duck samples is an example. While the cotton duck performed consistently in both test programs, it also yielded different results, presumably because of the difference in density between the two samples. CPSC staff believes that this observation, along with the demonstration that quantifiable results are obtainable, indicates the need for upgrading the requirements in at least some UL standards. Threshold heat flux requirements could be required for many products and would improve upon the robustness of the current requirements that rely on physical fire indicators.

CPSC staff is continuing this project in FY04 and conducting a review of UL standards to determine which ones have similar requirements that would be affected by this testing. For example, some standards specify that the fire indicator be placed in direct contact with the product being tested; this scenario was not evaluated here. Alternately, some fire indicators are used to indicate very transient heating conditions (i.e. arcs, sparks) and would also not be affected by these results. Only requirements that use a material to indicate non-piloted radiant ignition would be affected by these two test programs.

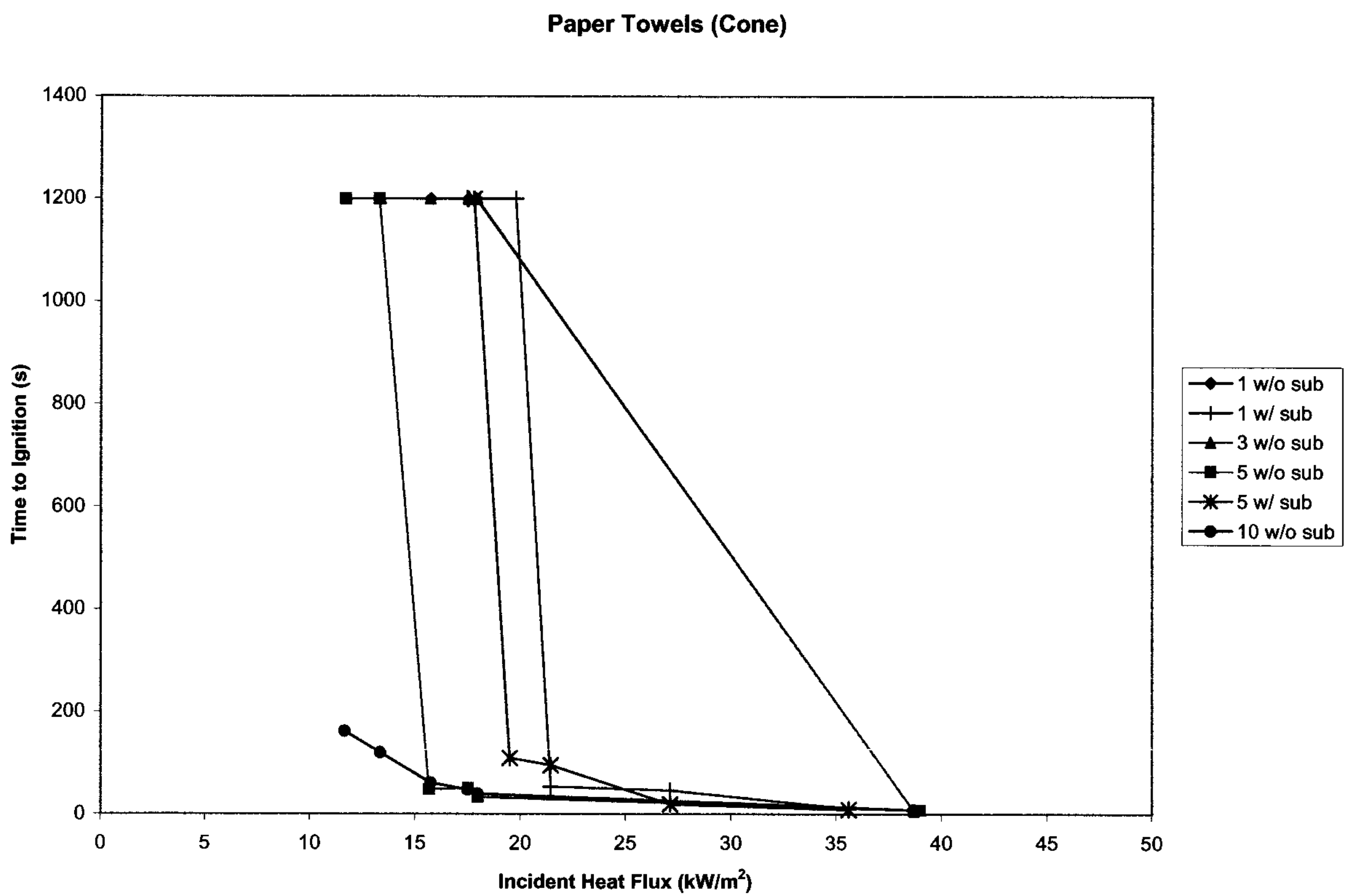
Once the review is completed, and the nature of the risks addressed by each standard is determined, efforts to incorporate quantifiable tests of the risk of ignition can begin on a prioritized basis. This effort will require identifying the types and configurations of common household combustibles likely to be exposed to the risk of ignition for each type of product. It will also require assessing the typical use and foreseeable misuse of each product. Additional test work to determine the types and configurations of potential combustibles may be required to develop acceptance criteria for the product under consideration.



1.ConeCheesecloth

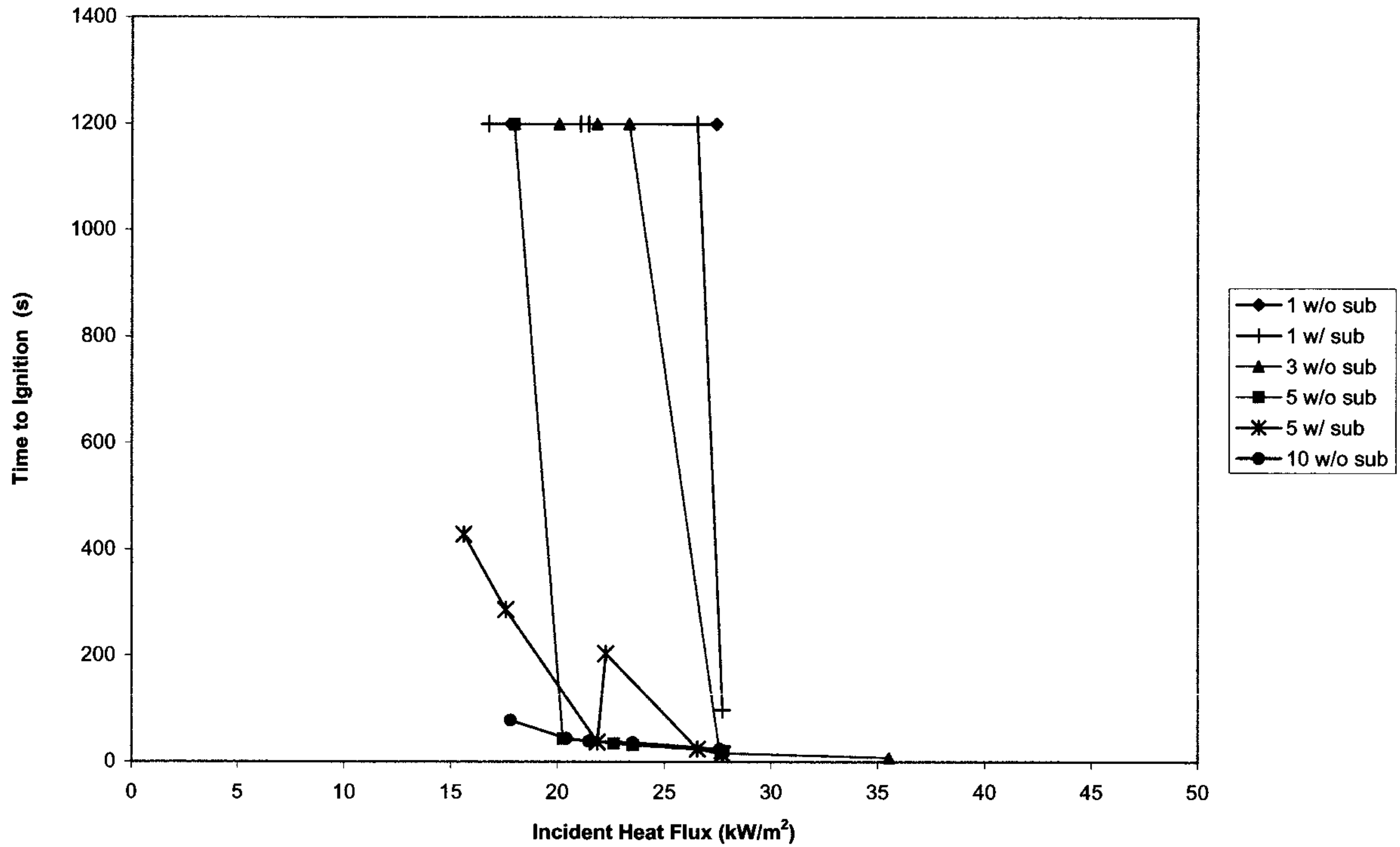


2.LIFTCheesecloth



3.ConePaperTowels

Paper Towel (LIFT)



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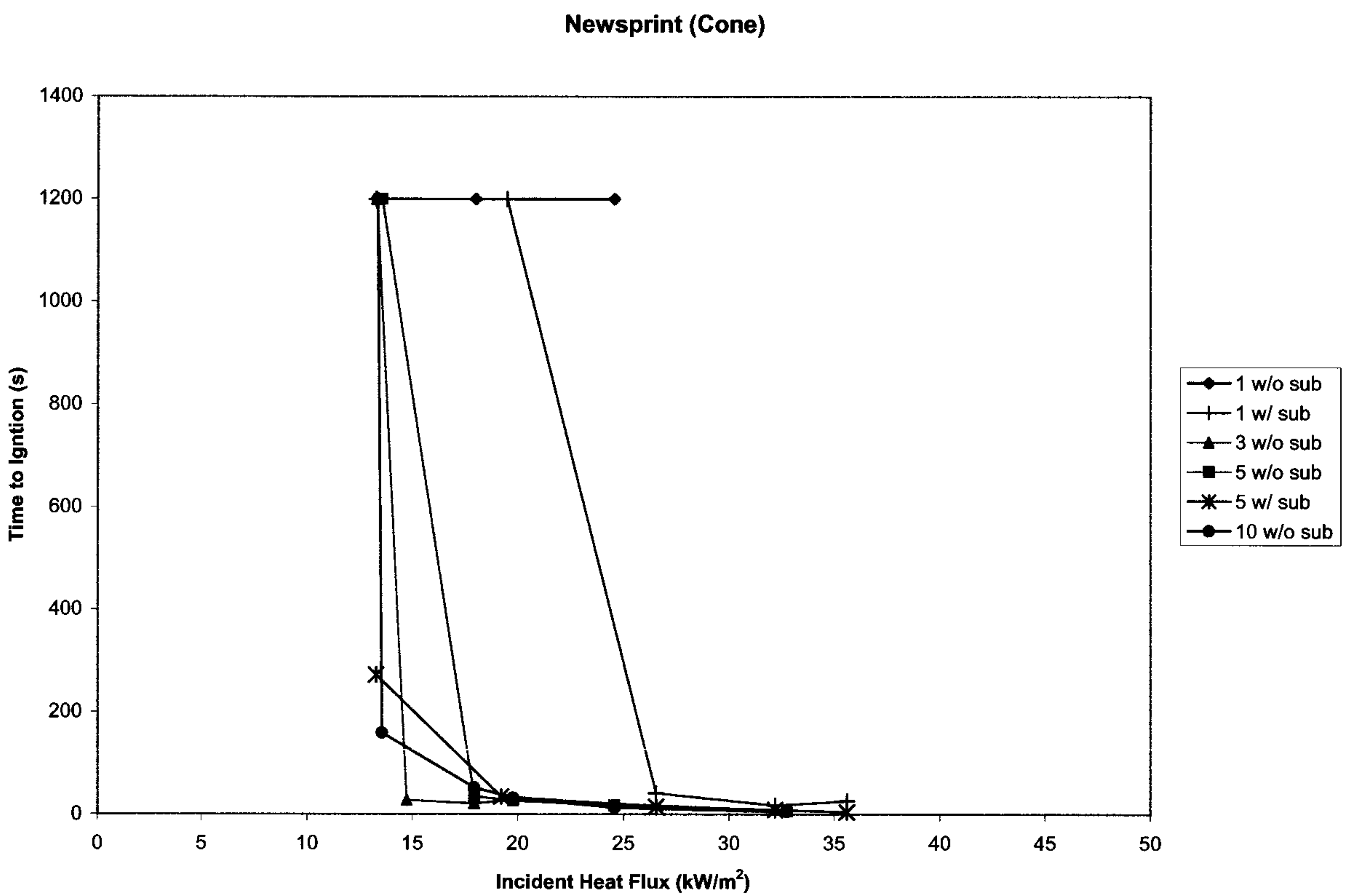
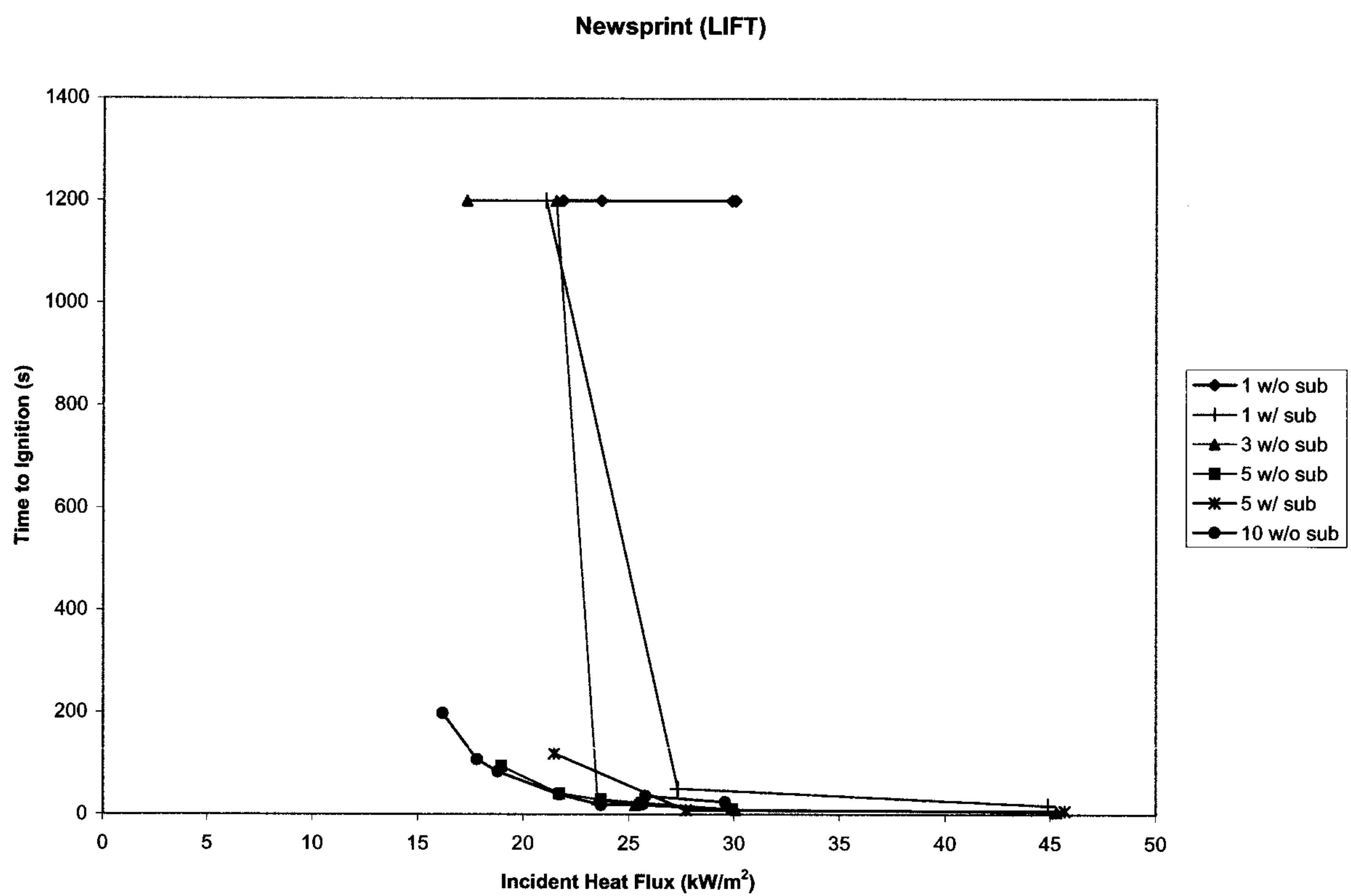
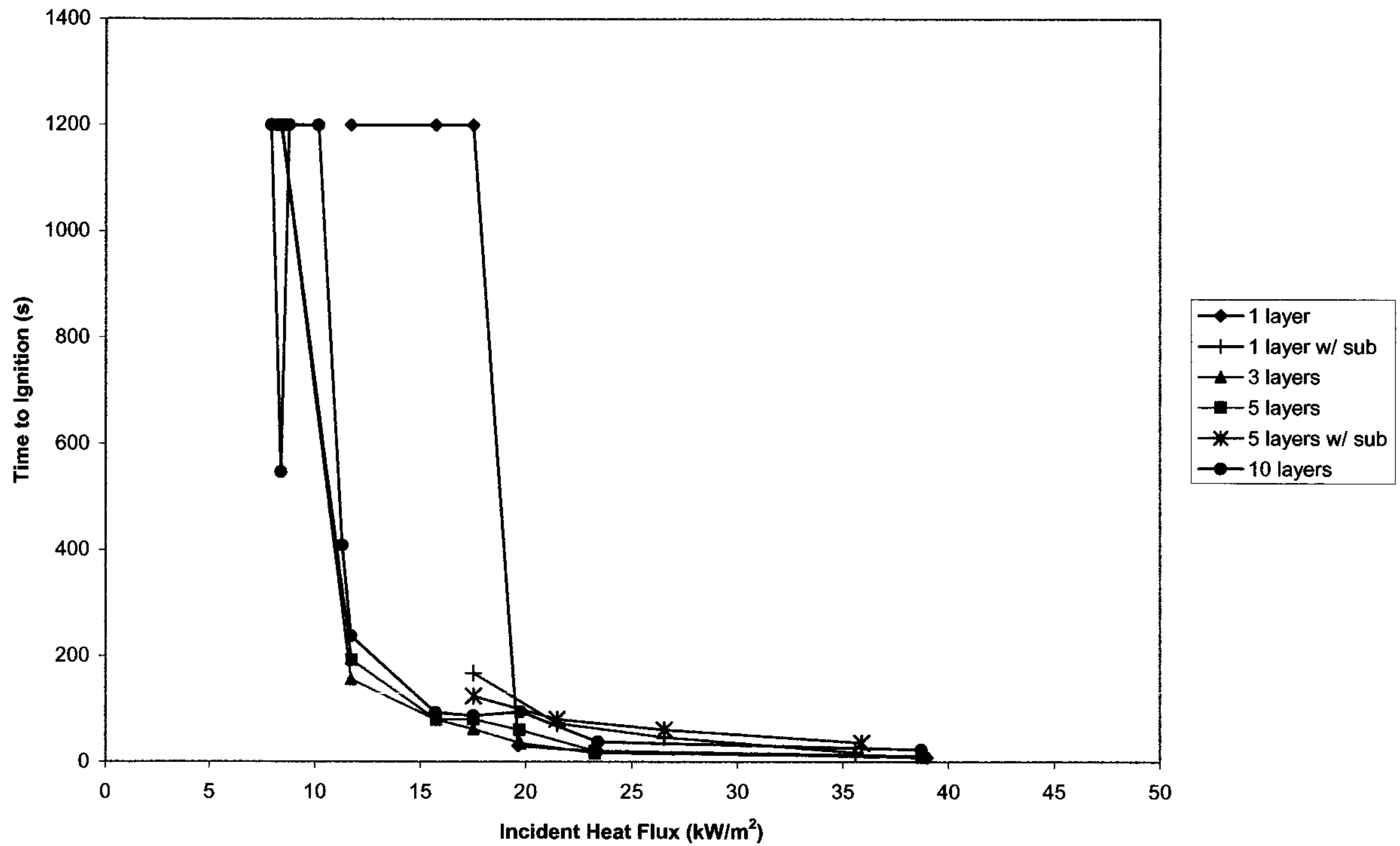


5.ConeNewsprint



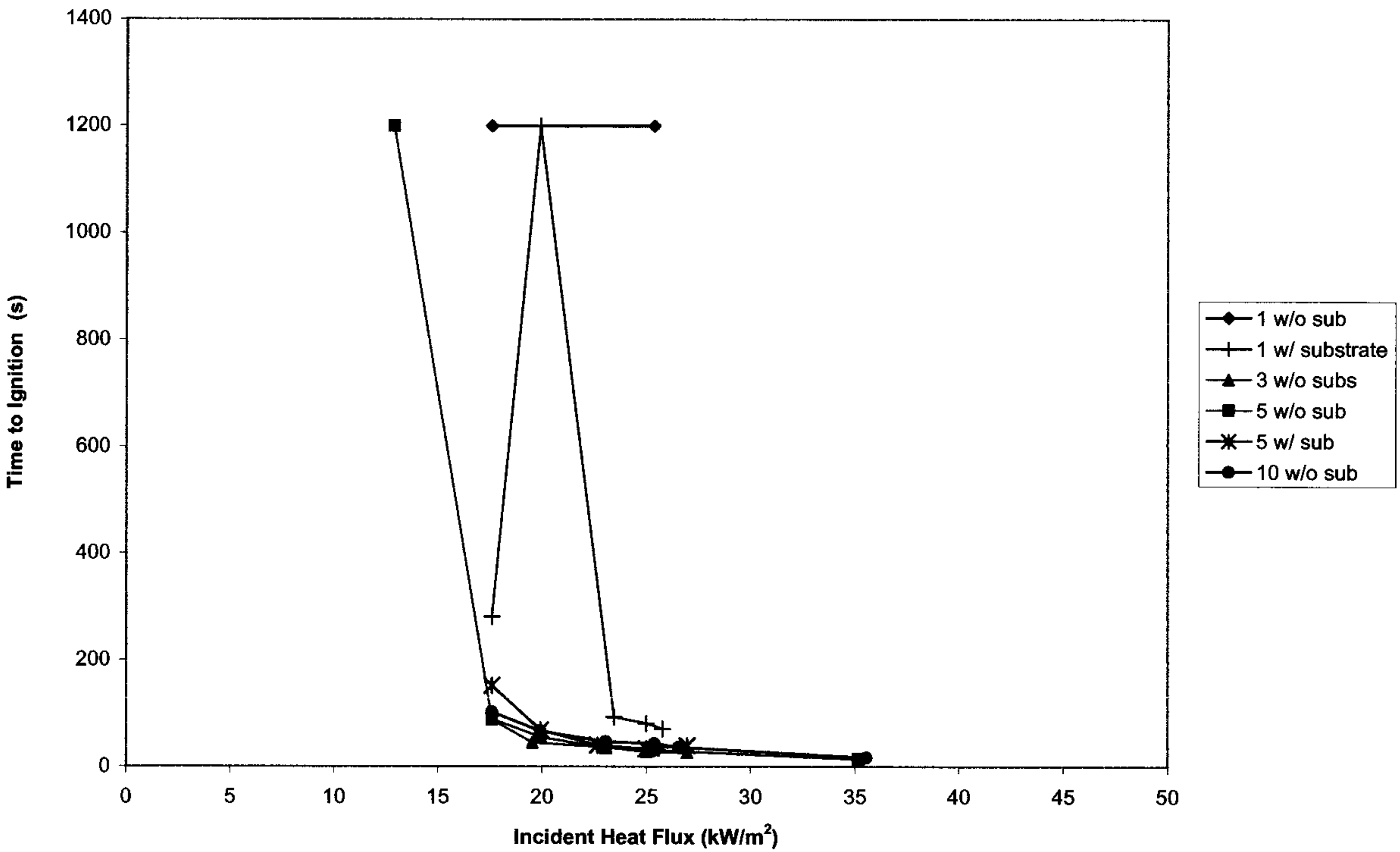
6.LIFTNewsprint

Bed Sheets (Cone)



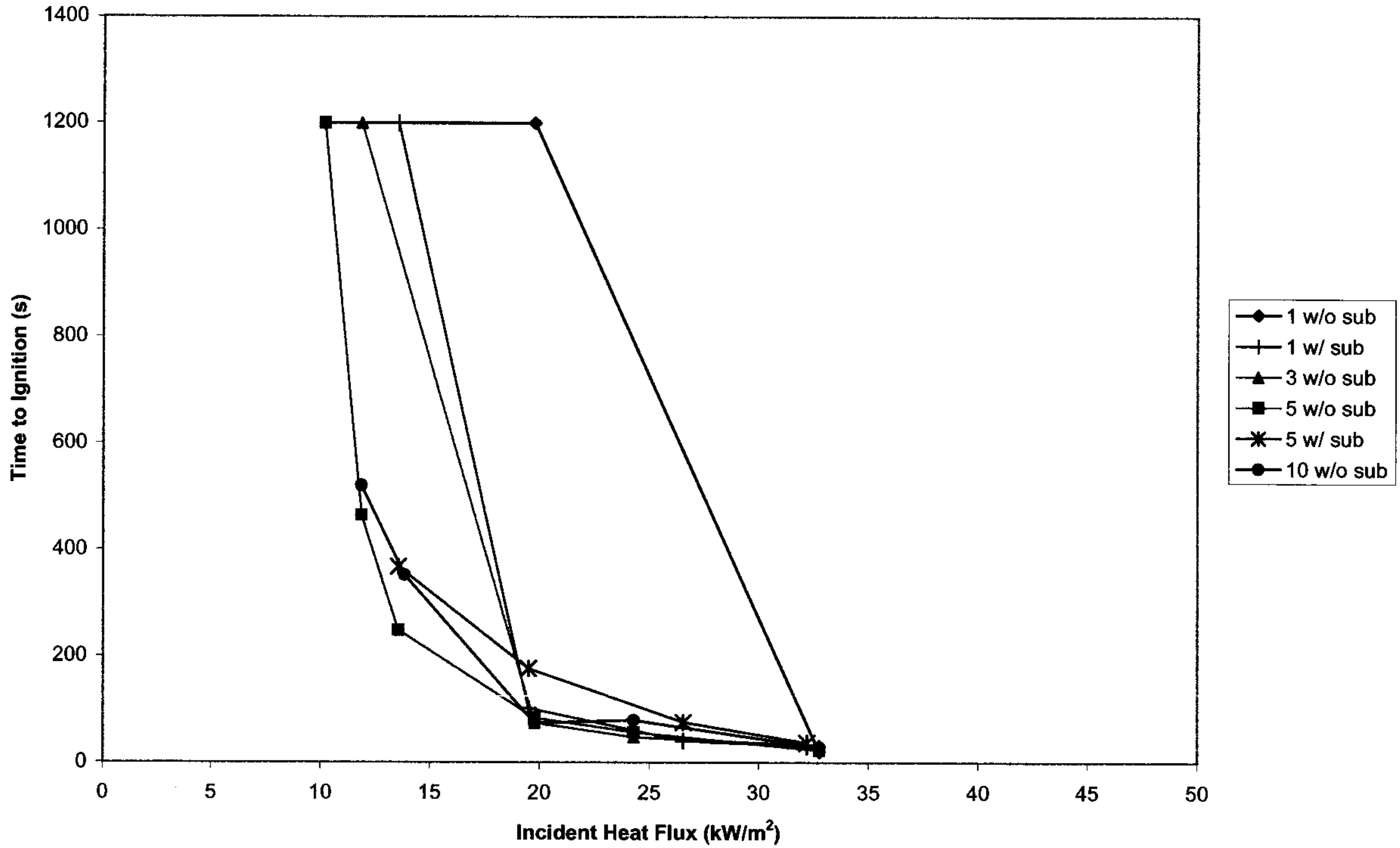
7.ConeBedSheets

Bed Sheets (LIFT)

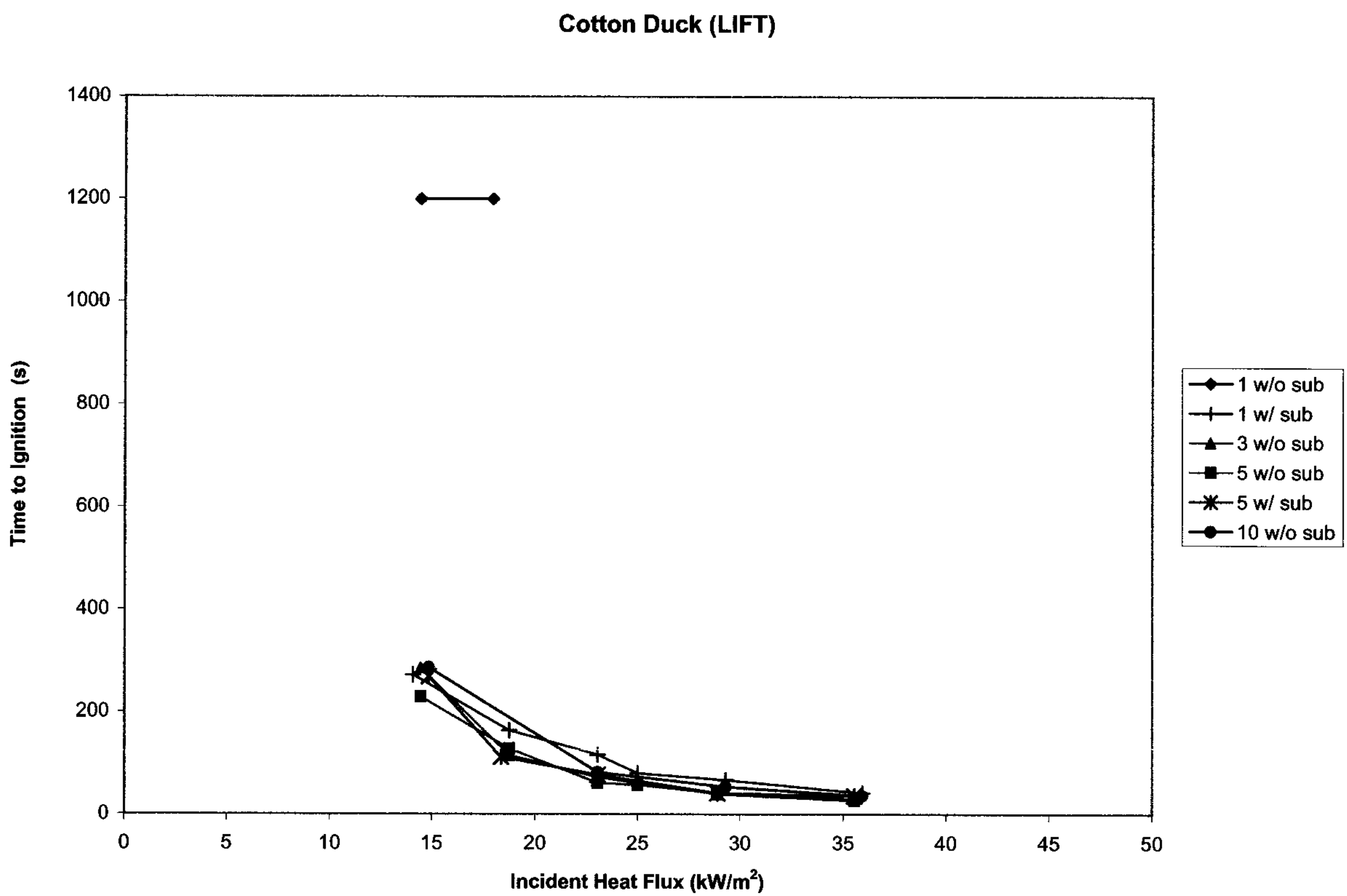


8.LIFTBedsheets

Cotton Duck (Cone)

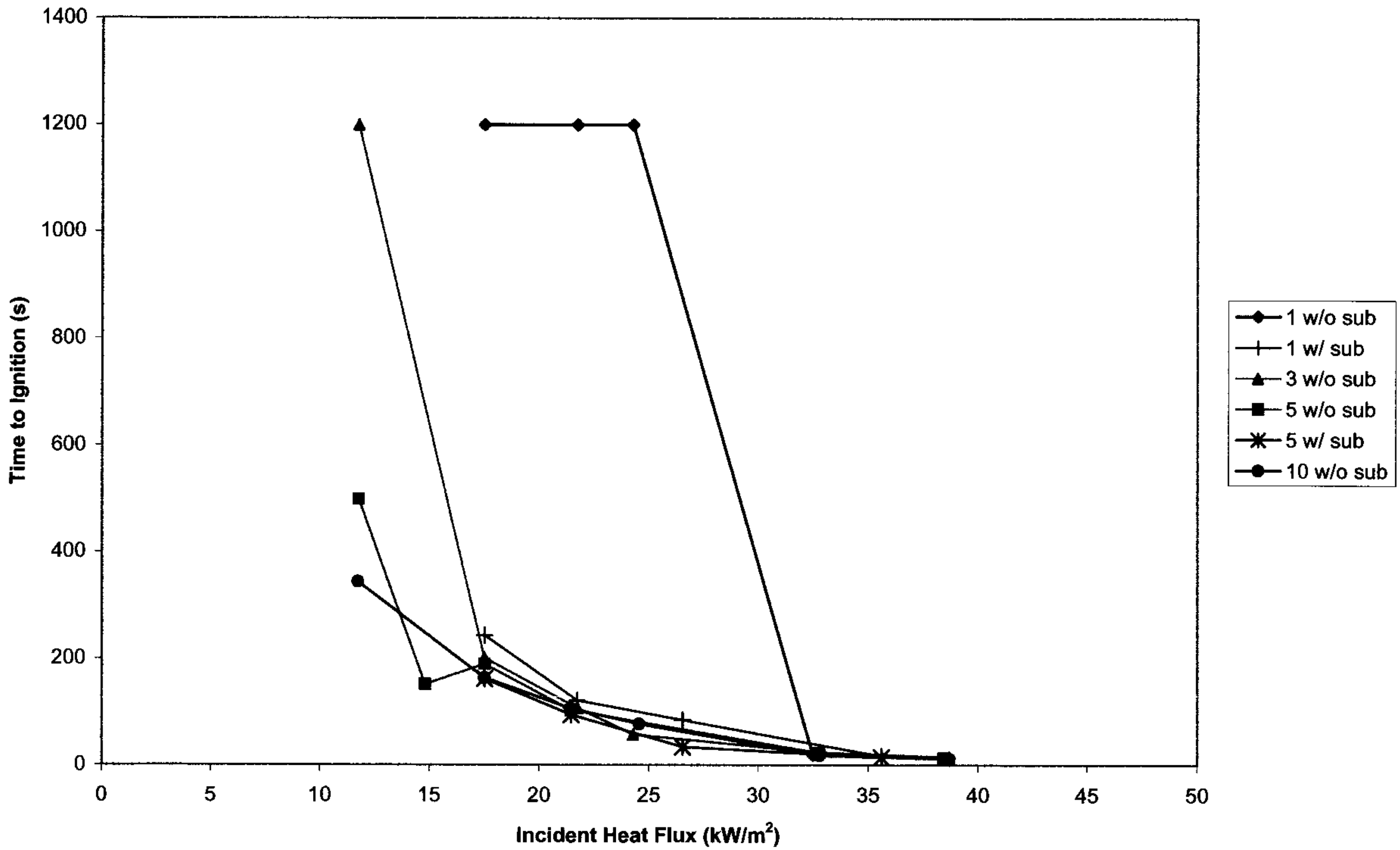


9.ConeDuck

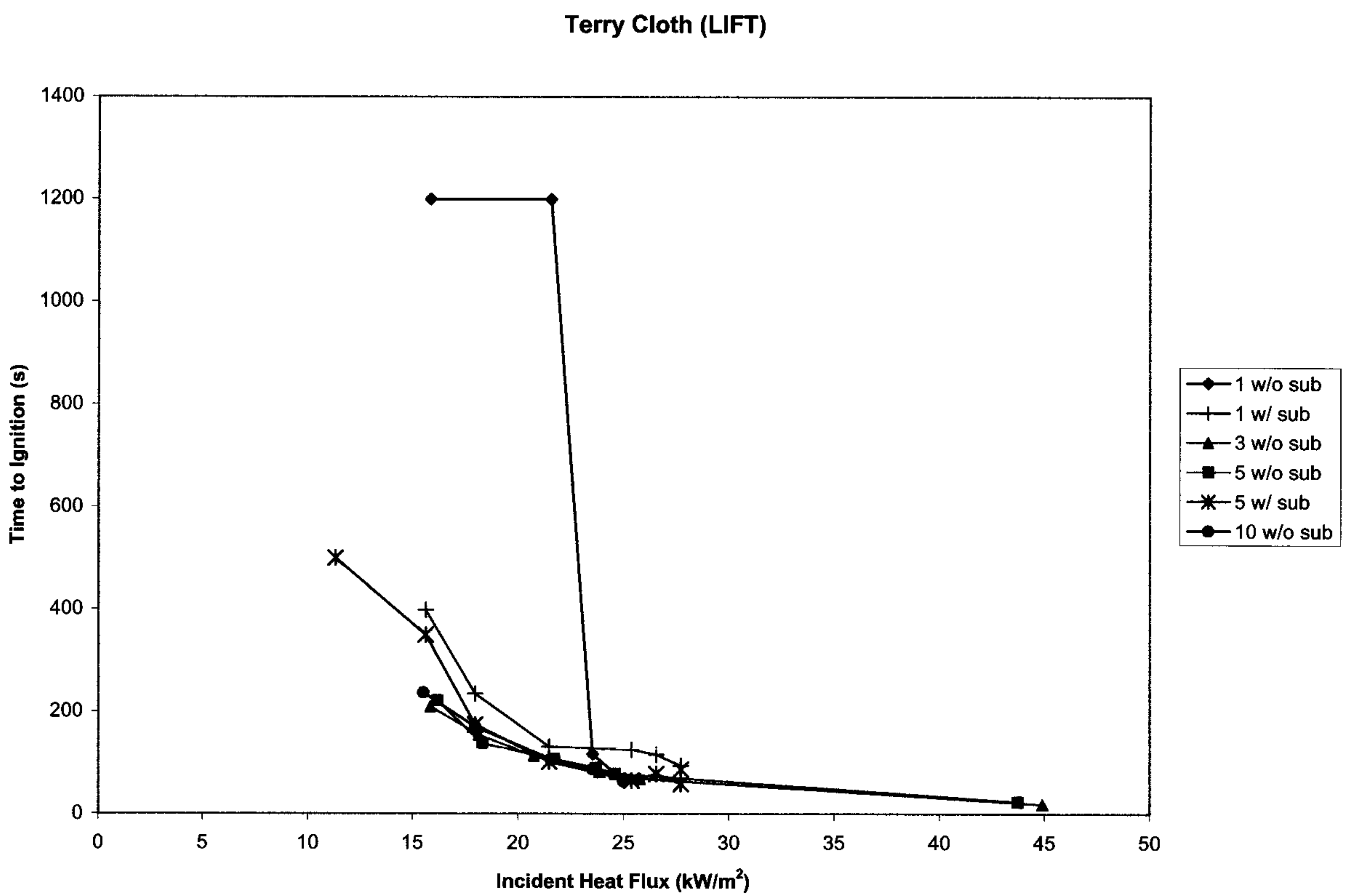

Cotton Duck (LIFT)
Time to Ignition (s)
1400
1200
1000
800
600
400
200
0
0
5
10
15
20
25
30
35
40
45
50
Incident Heat Flux (kW/m^2)
1 w/o sub
1 w/ sub
3 w/o sub
5 w/o sub
5 w/ sub
10 w/o sub

10.LIFTDuck

Terry Cloth (Cone)

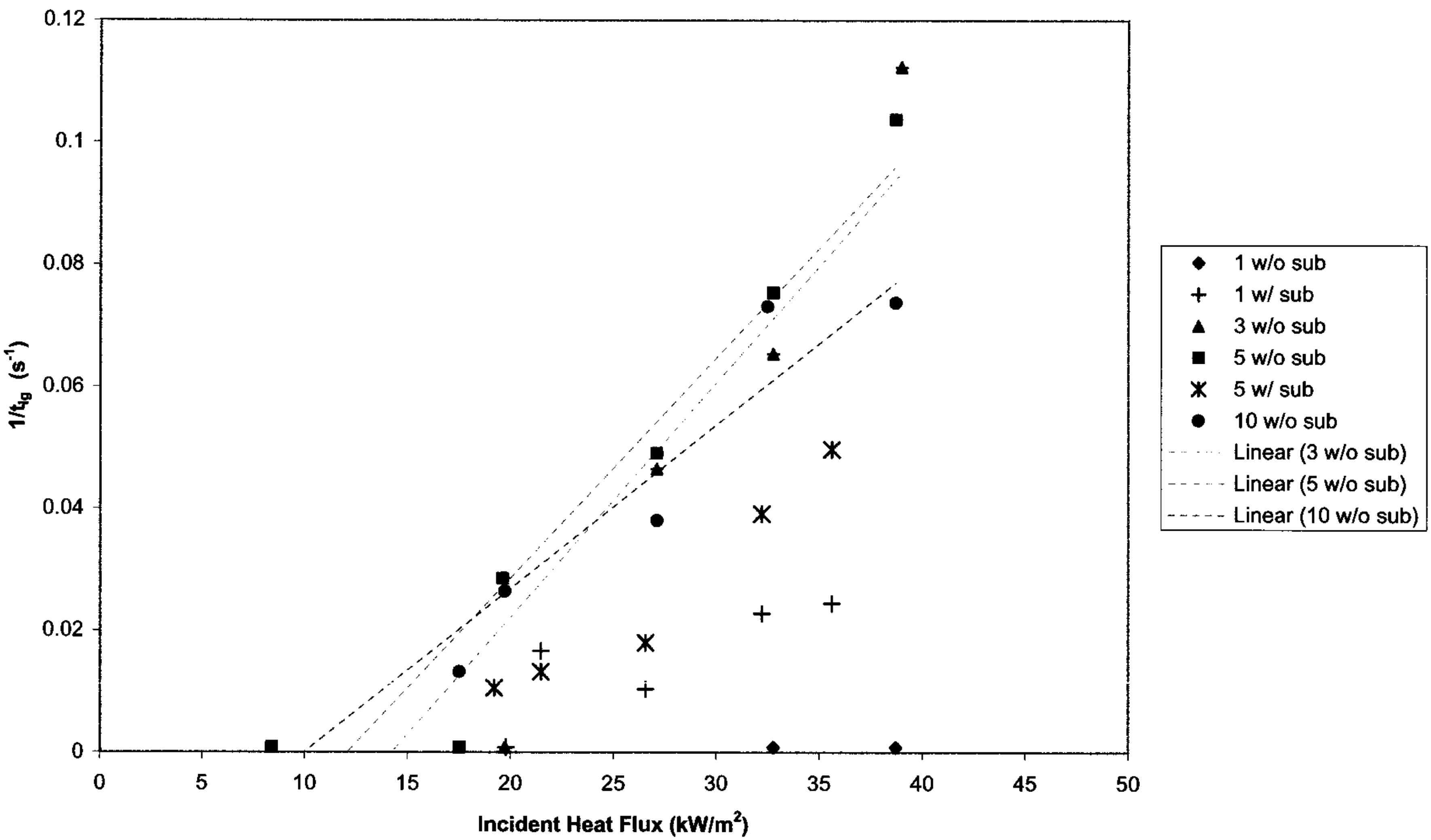


11.ConeTerry



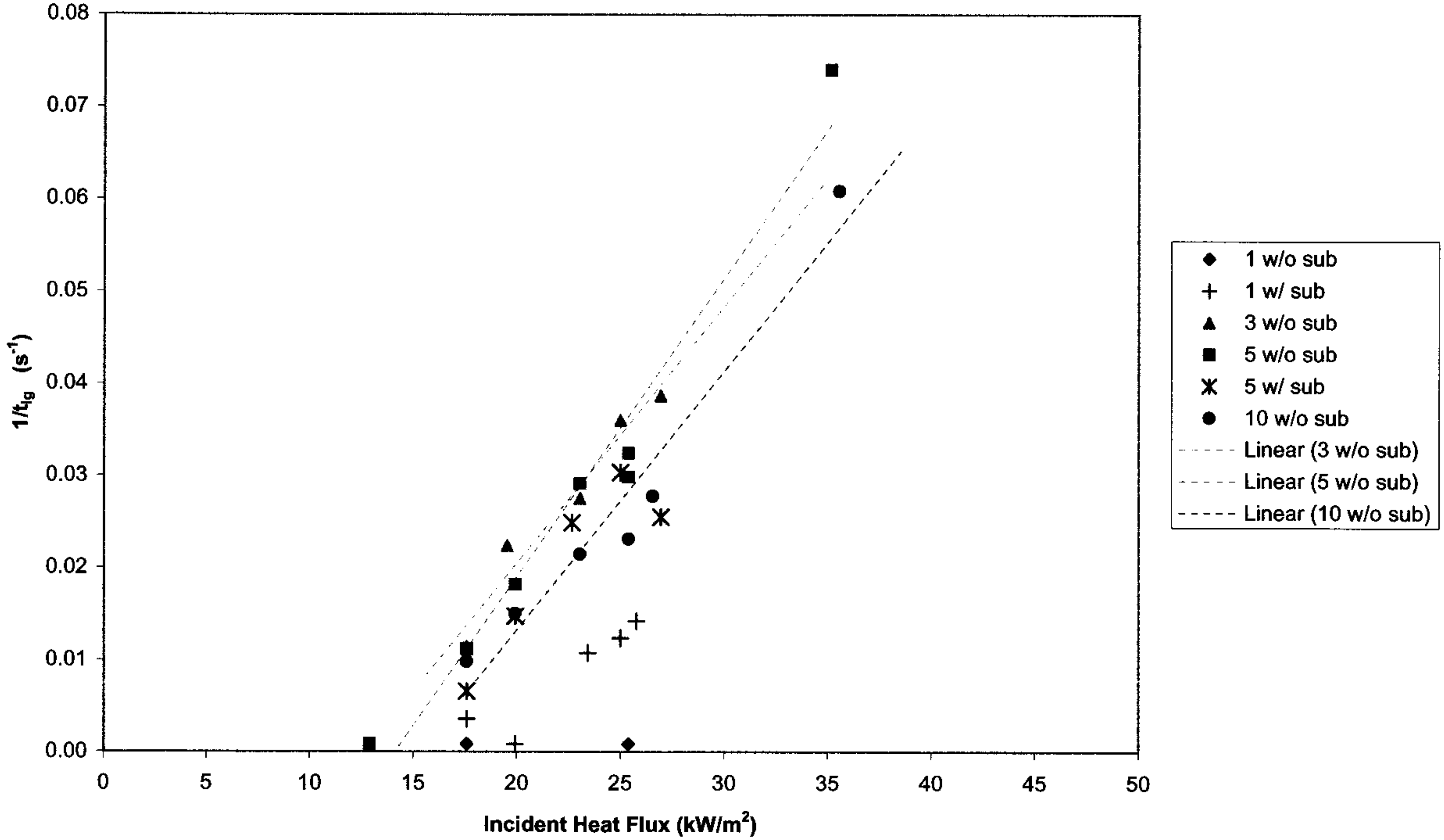
12.LIFTTerry

Cheesecloth (Cone)
Thermally Thin Analysis



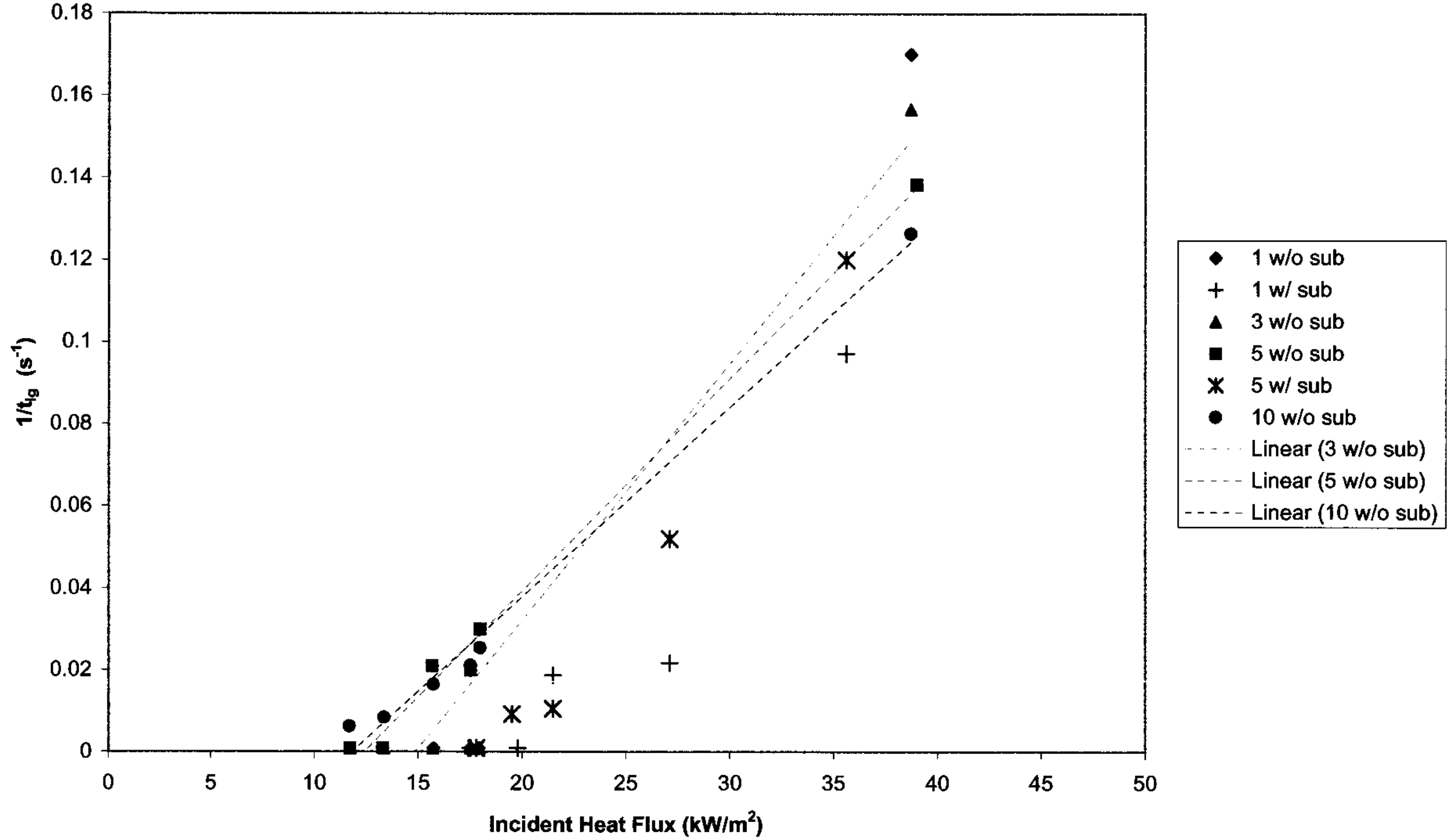
13.ConeCheeseclothThin

Cheesecloth (LIFT)
Thermally Thin Analysis



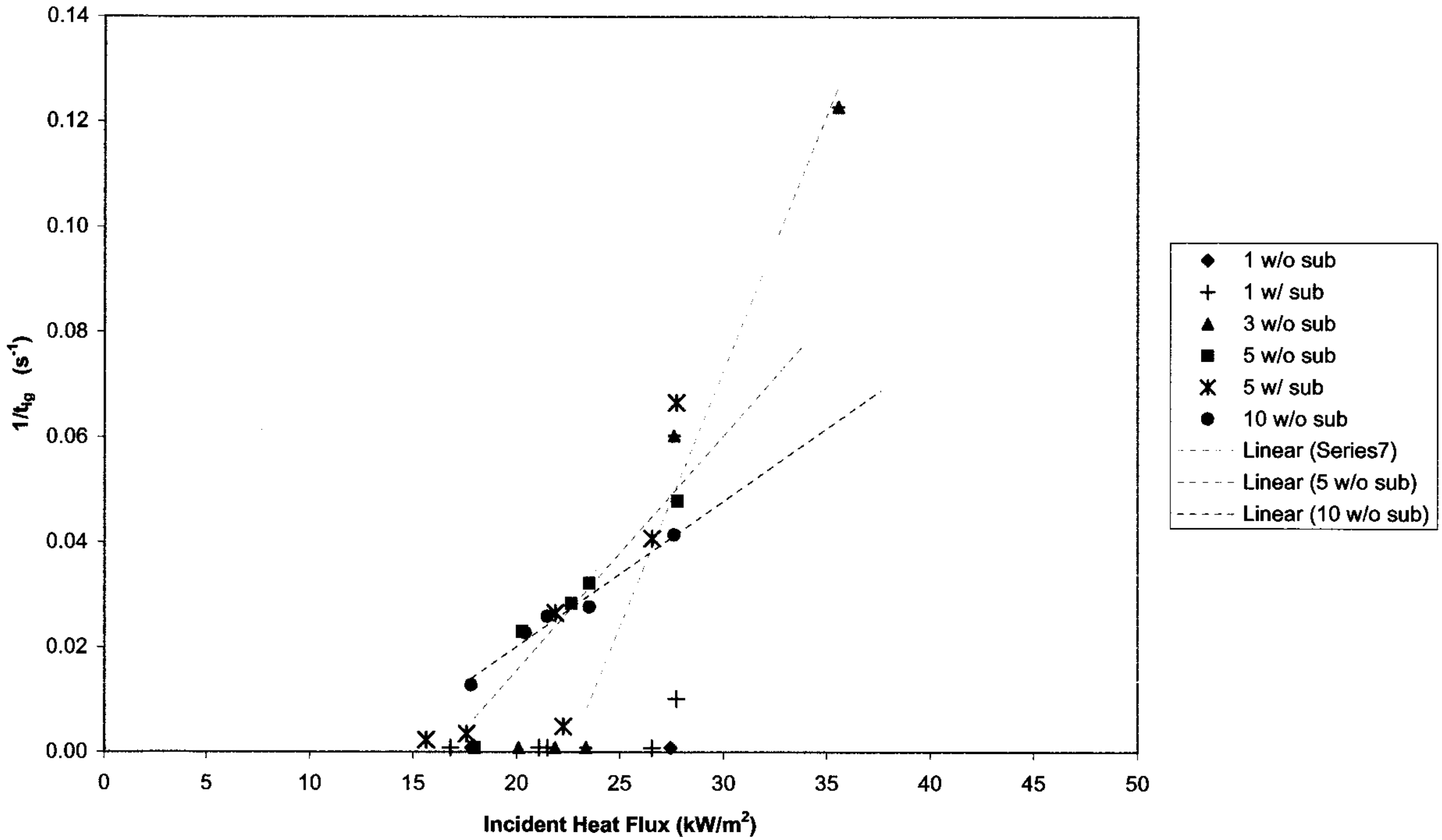
14.LIFTCheeseclothThin

Paper Towels (Cone)
Thermally Thin Analysis

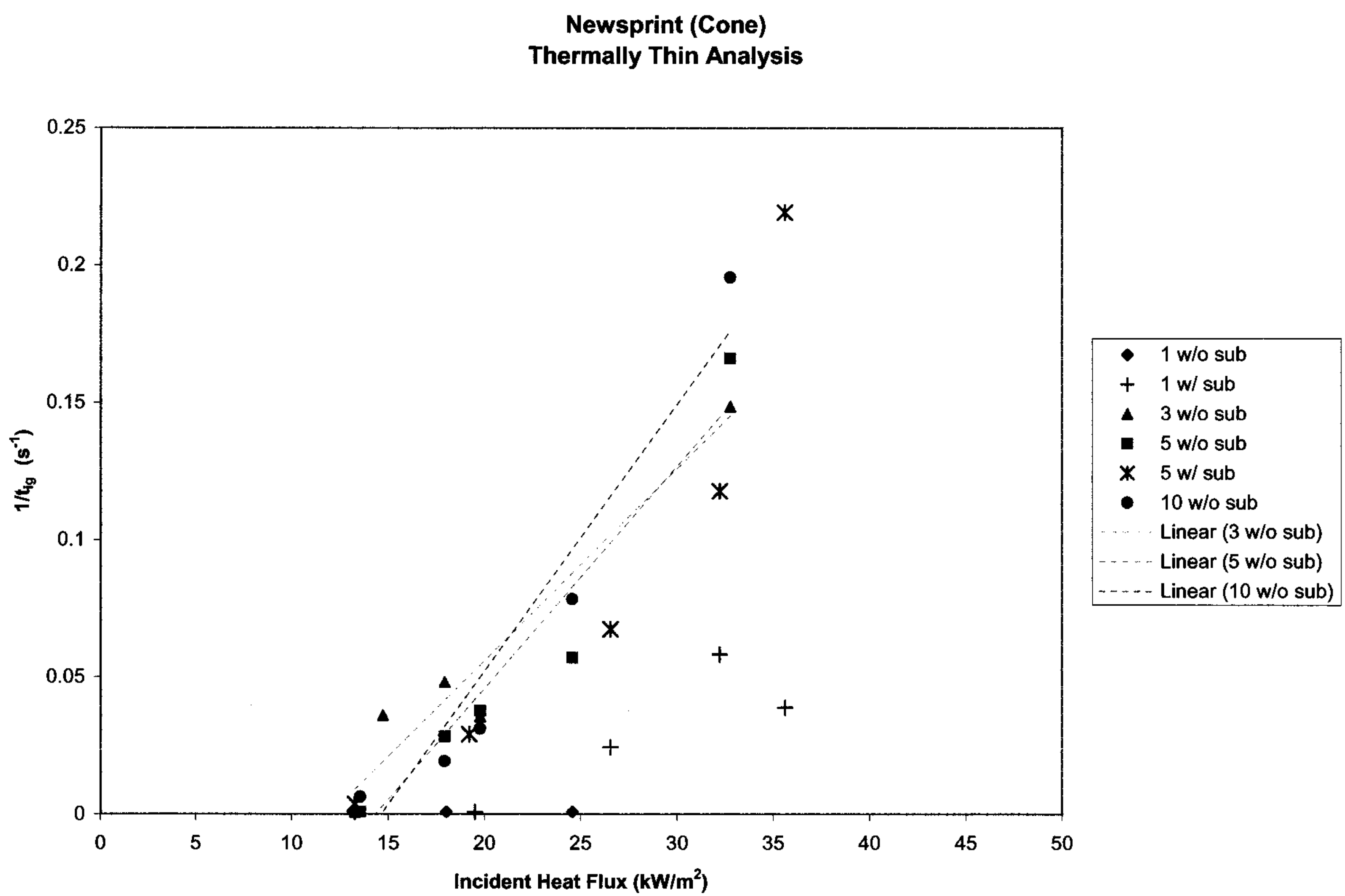


15.ConePaperTowelsThin

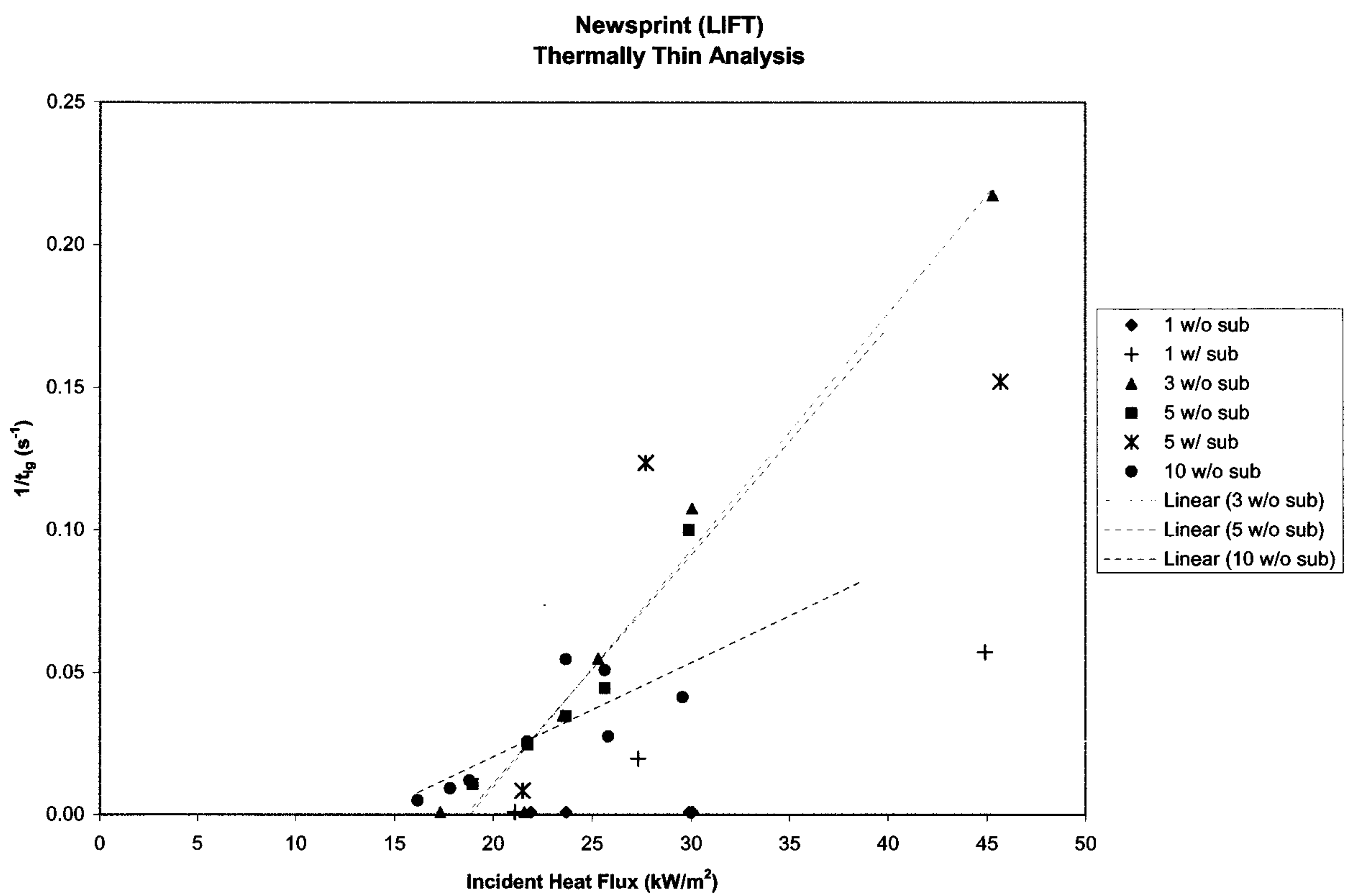
Paper Towel (LIFT)
Thermally Thin Analysis



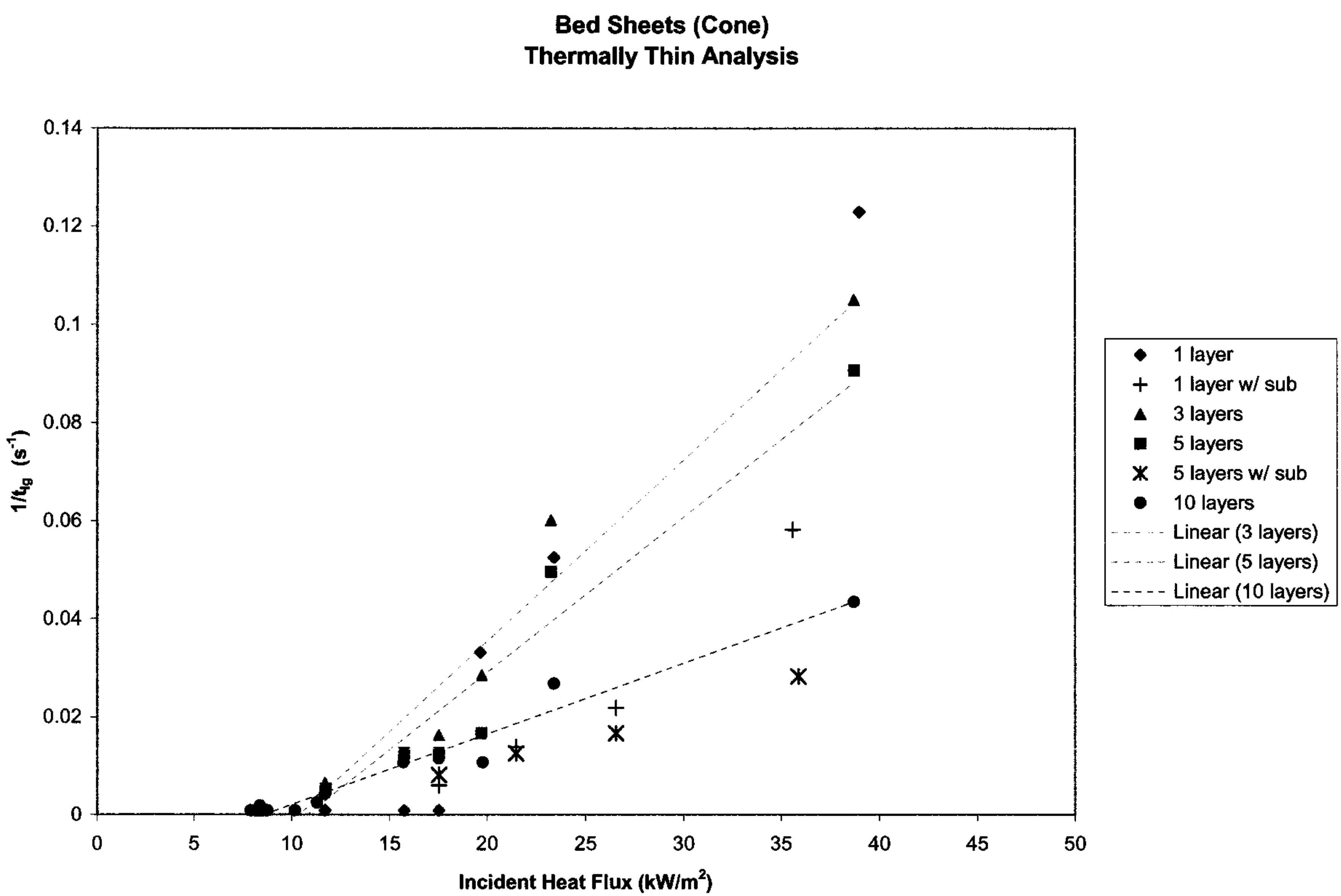
16.LIFTPaperTowelThin



17.ConeNewsprintThin

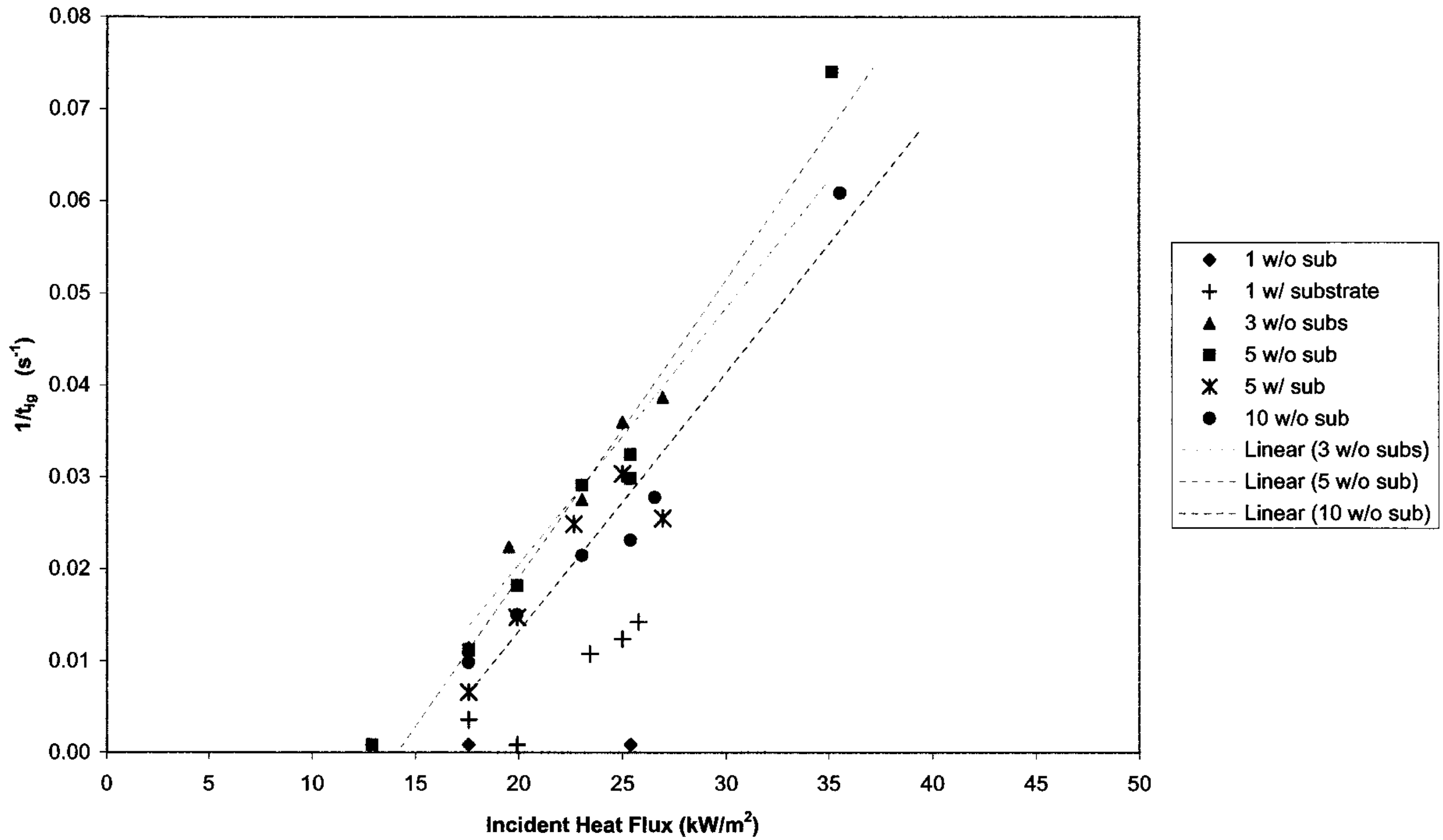


18.LIFTNewsprintThin



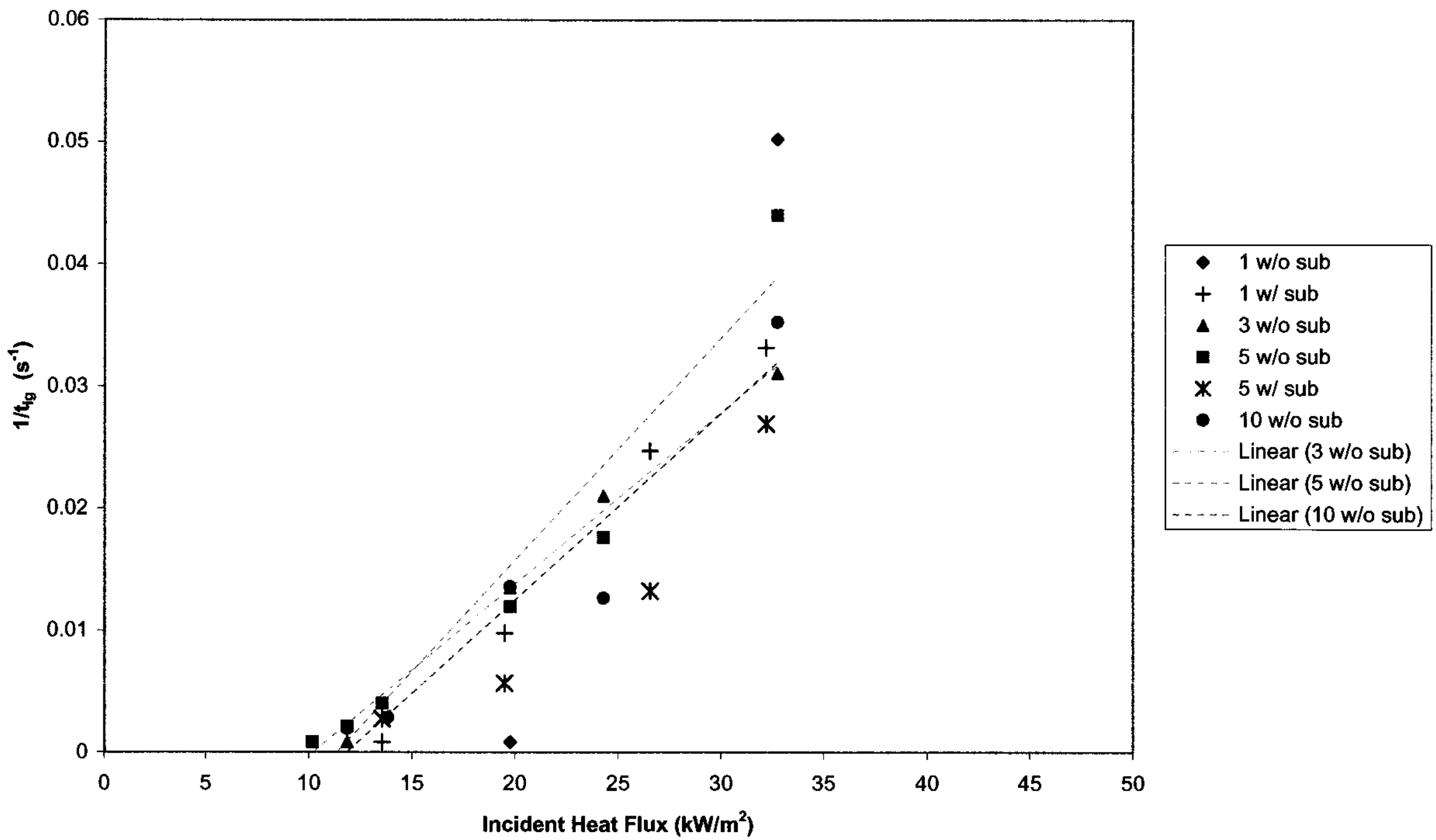
19.ConeBedSheetsThin

Bed Sheets (LIFT)
Thermally Thin Analysis



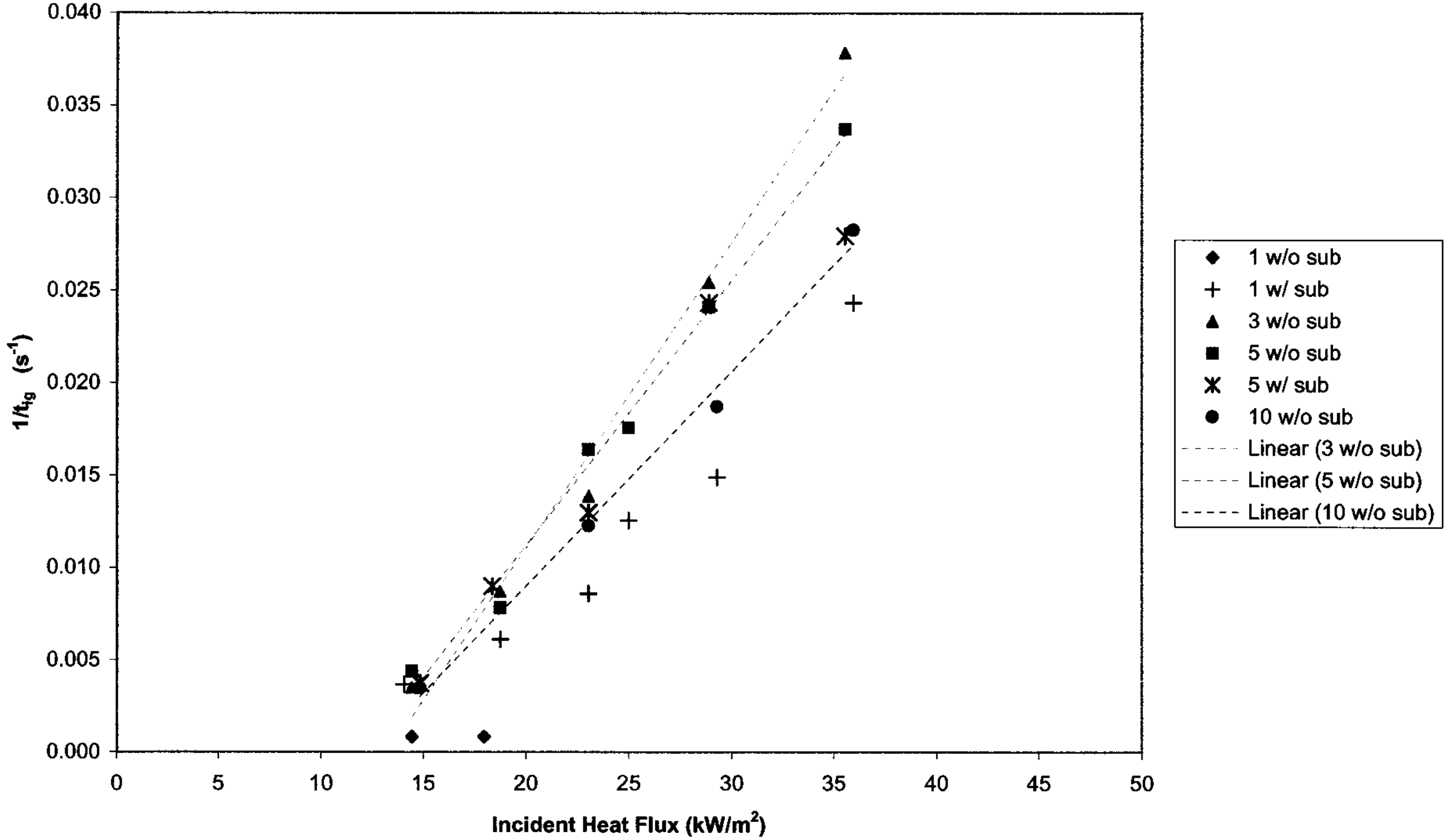
20.LIFTBedsheetsThin

Cotton Duck (Cone)
Thermally Thin Analysis

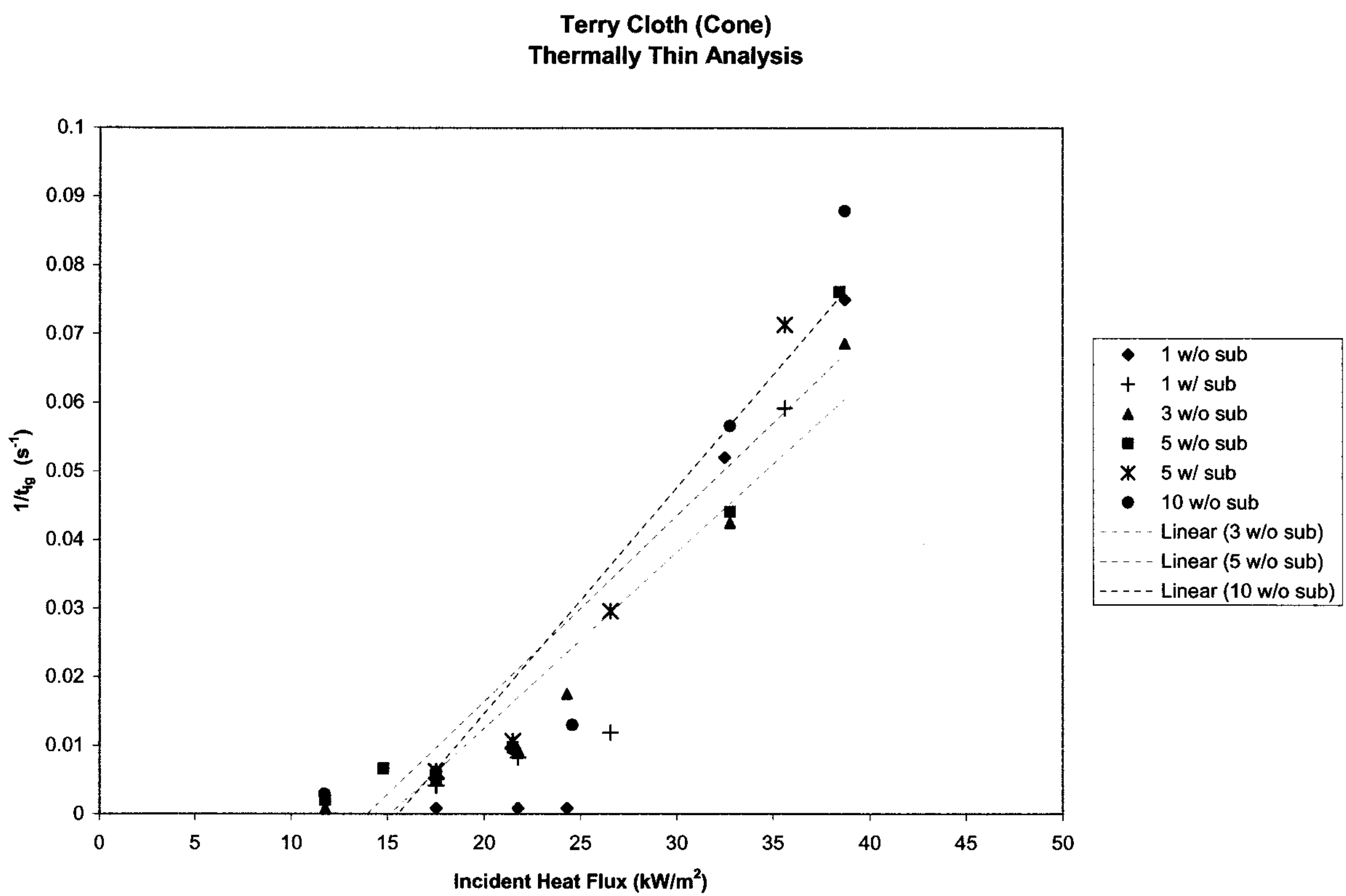


21.ConeDuckThin

Cotton Duck (LIFT)
Thermally Thin Analysis

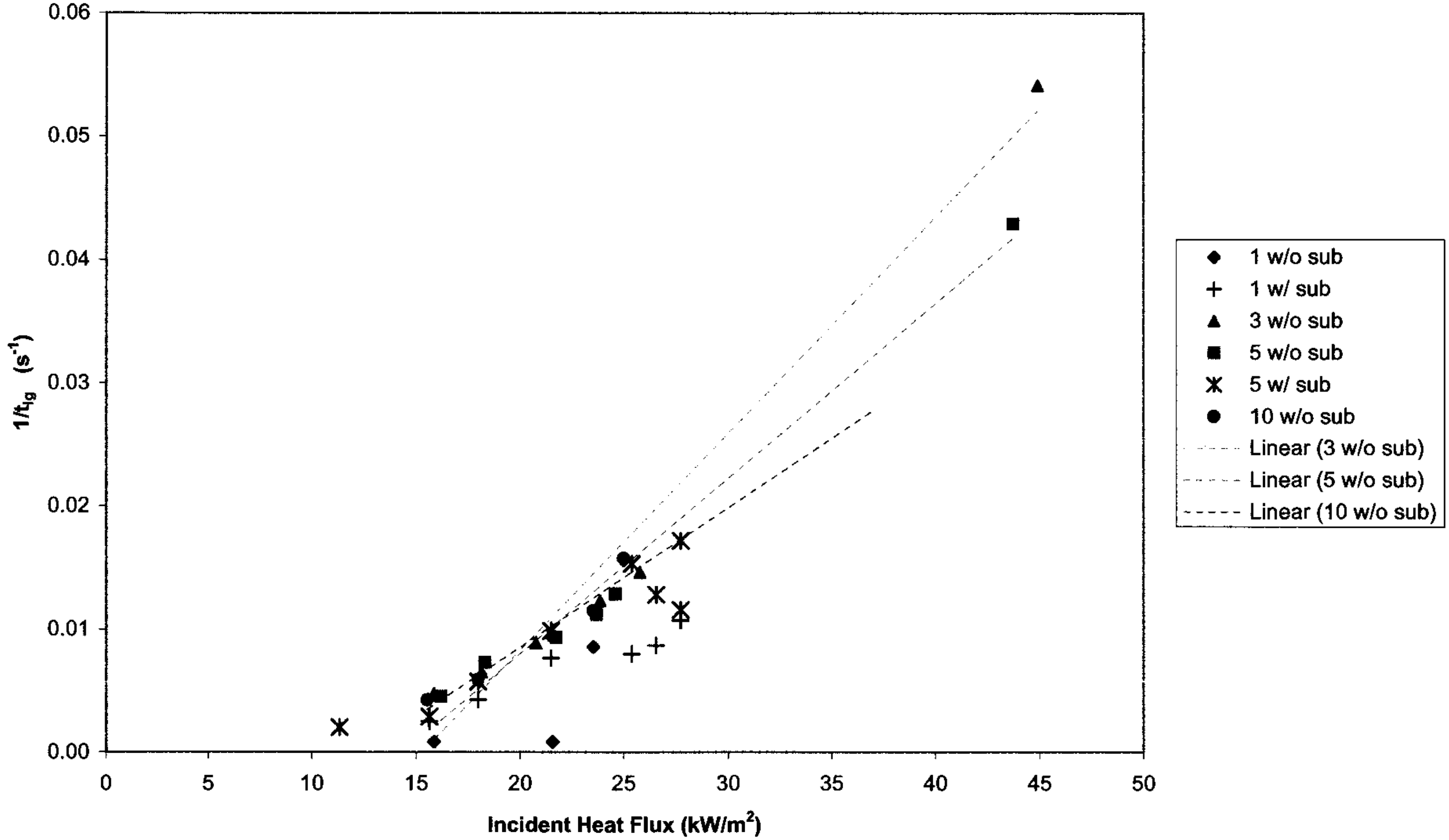


22.LIFTDuckThin



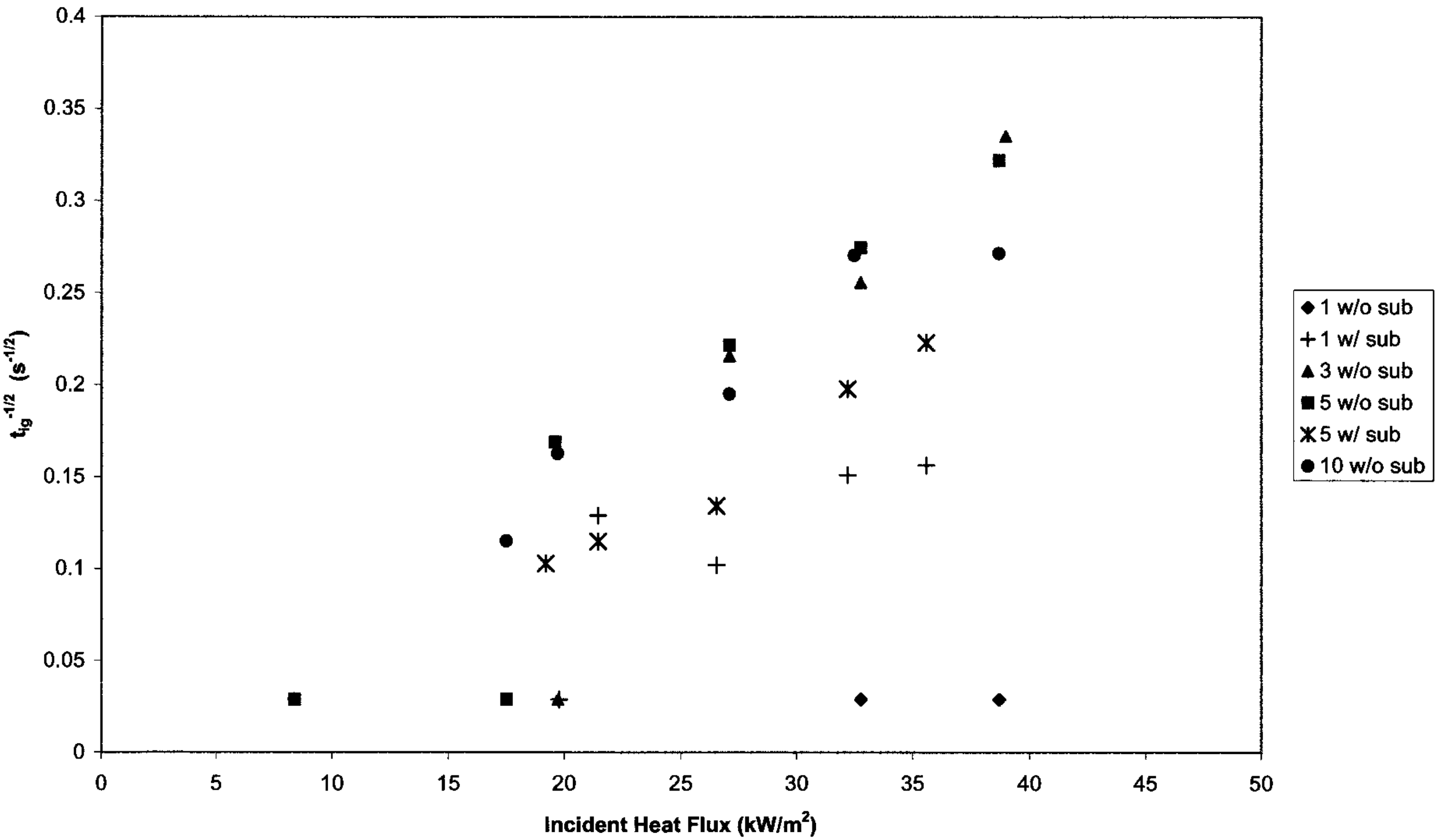
23.ConeTerryThin

Terry Cloth (LIFT)
Thermally Thin Analysis



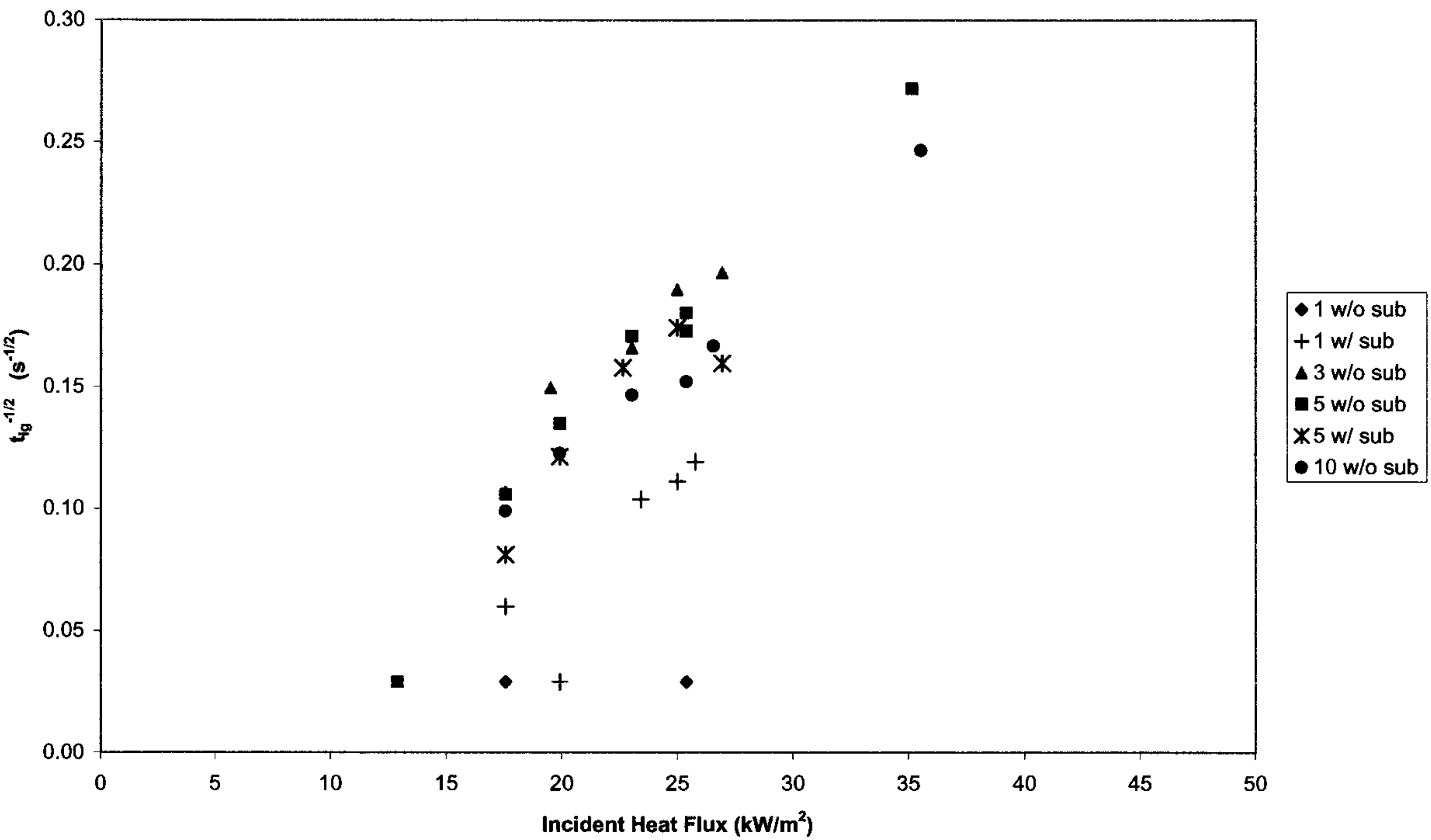
24.LIFTTerryThin

Cheesecloth (Cone)
Thermally Thick Analysis

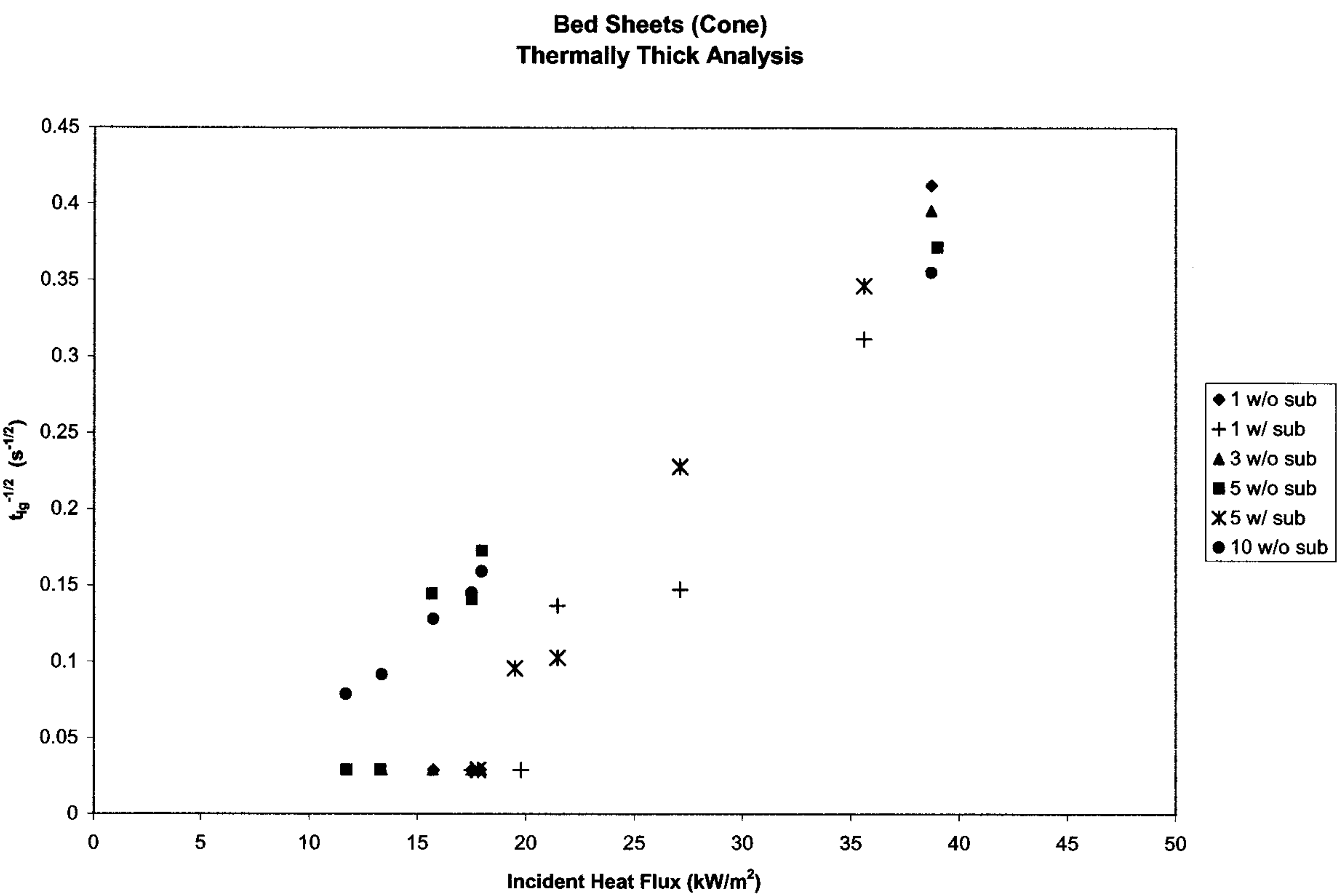


25.ConeCheeseclothThick

Cheesecloth (LIFT)
Thermally Thick Analysis

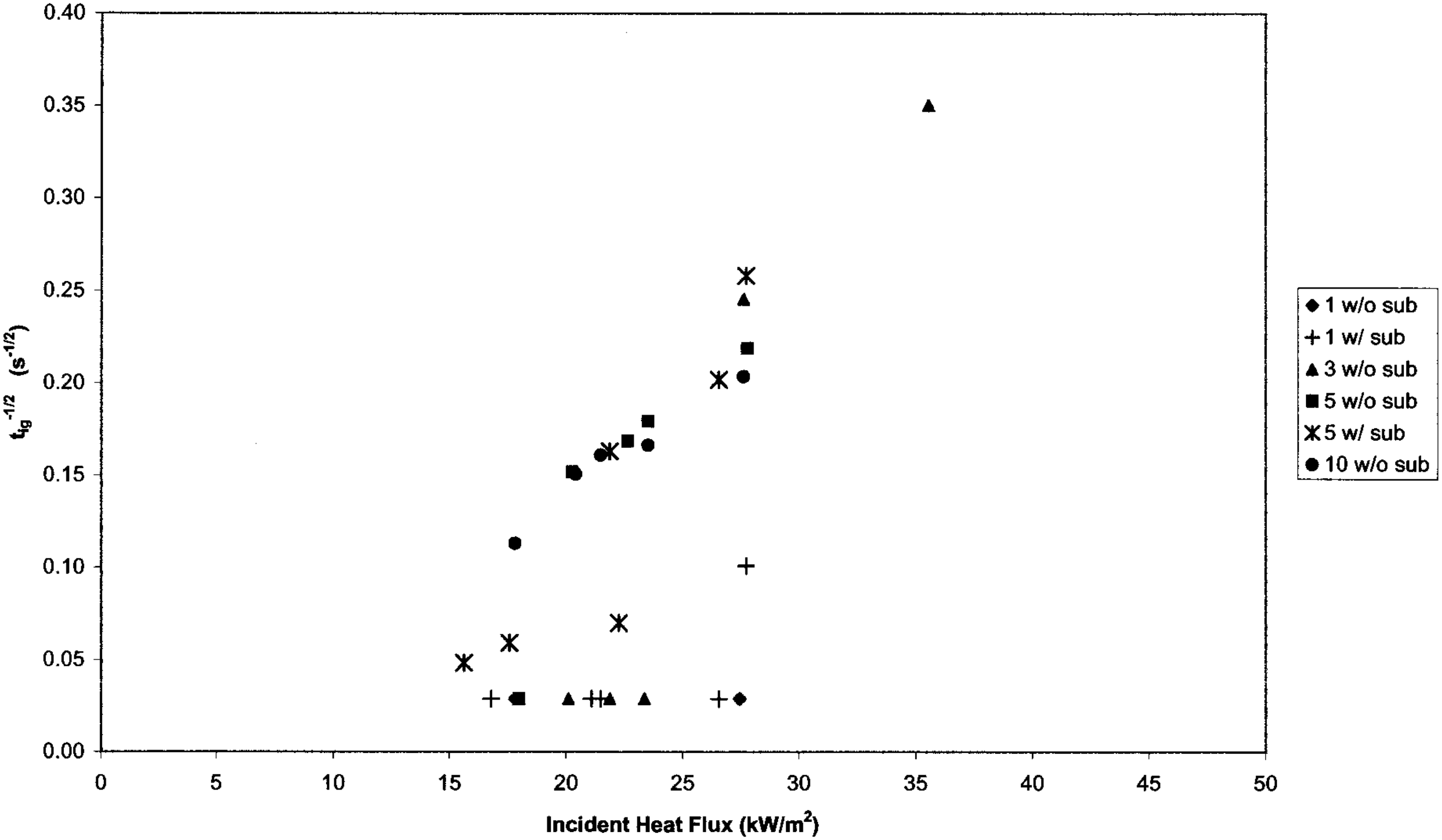


26.LIFTCheeseclothThick

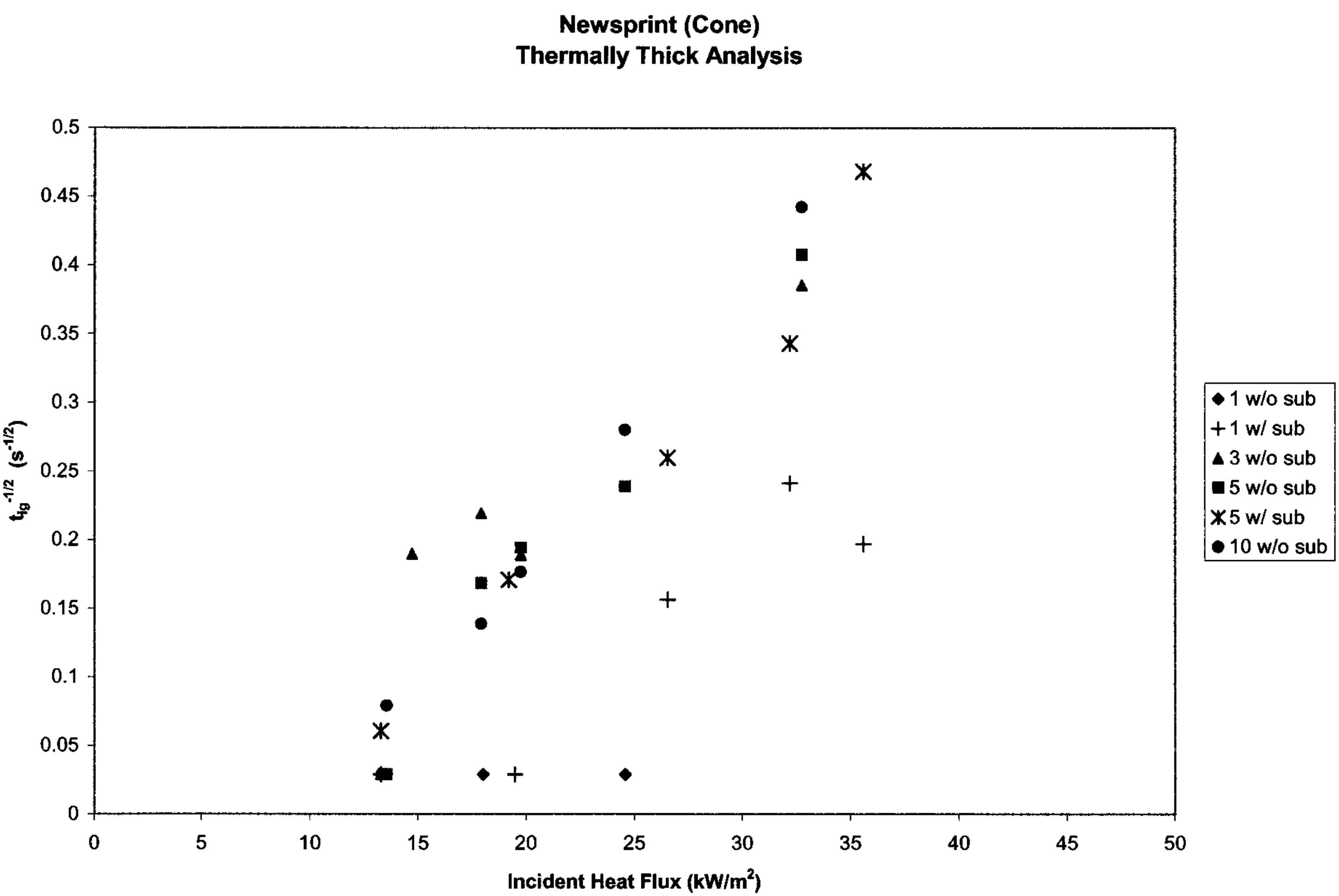


27.ConePaperTowelsThick

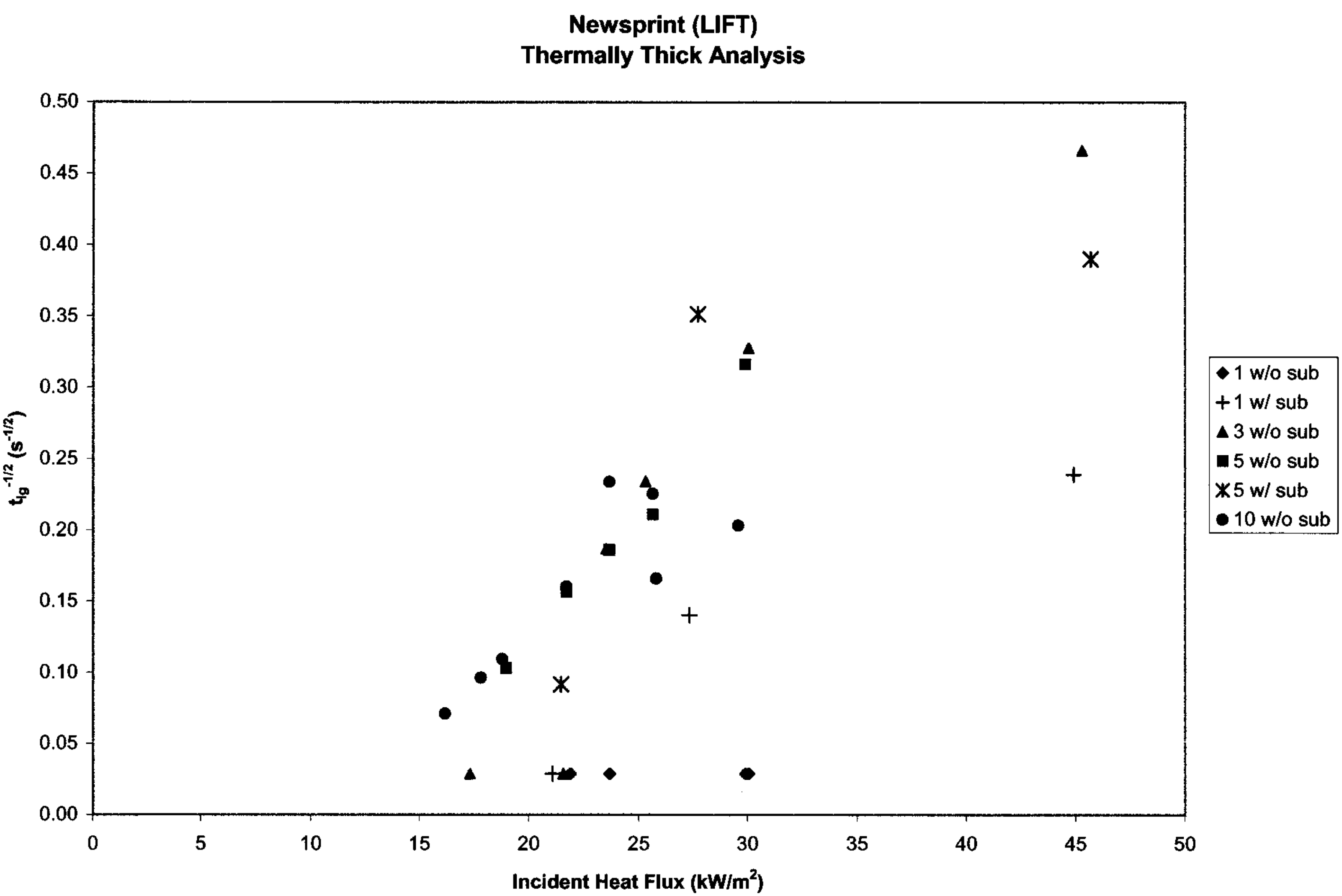
Paper Towel (LIFT)
Thermally Thick Analysis



28.LIFTPaperTowelThick

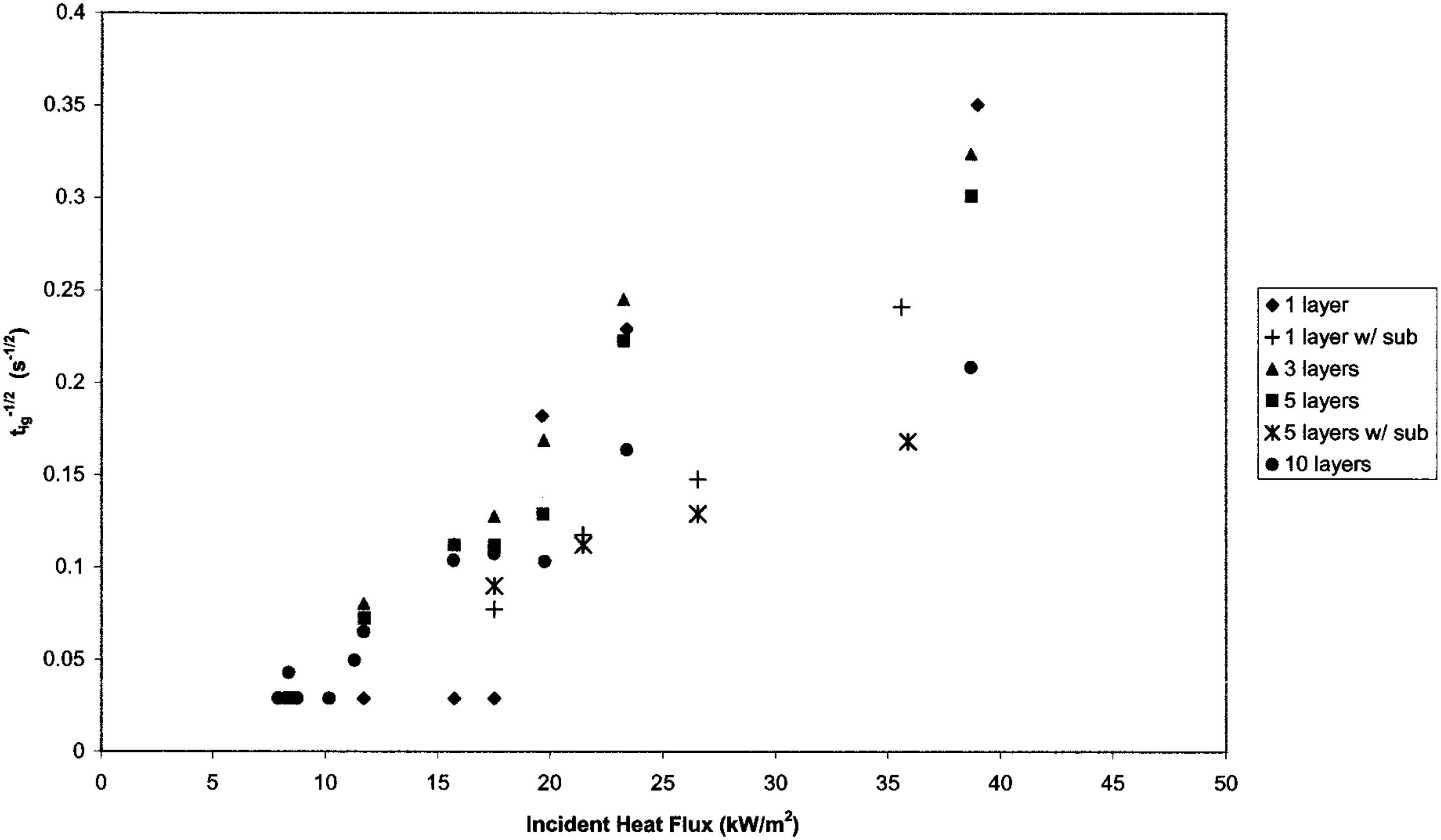


29.ConeNewsprintThick

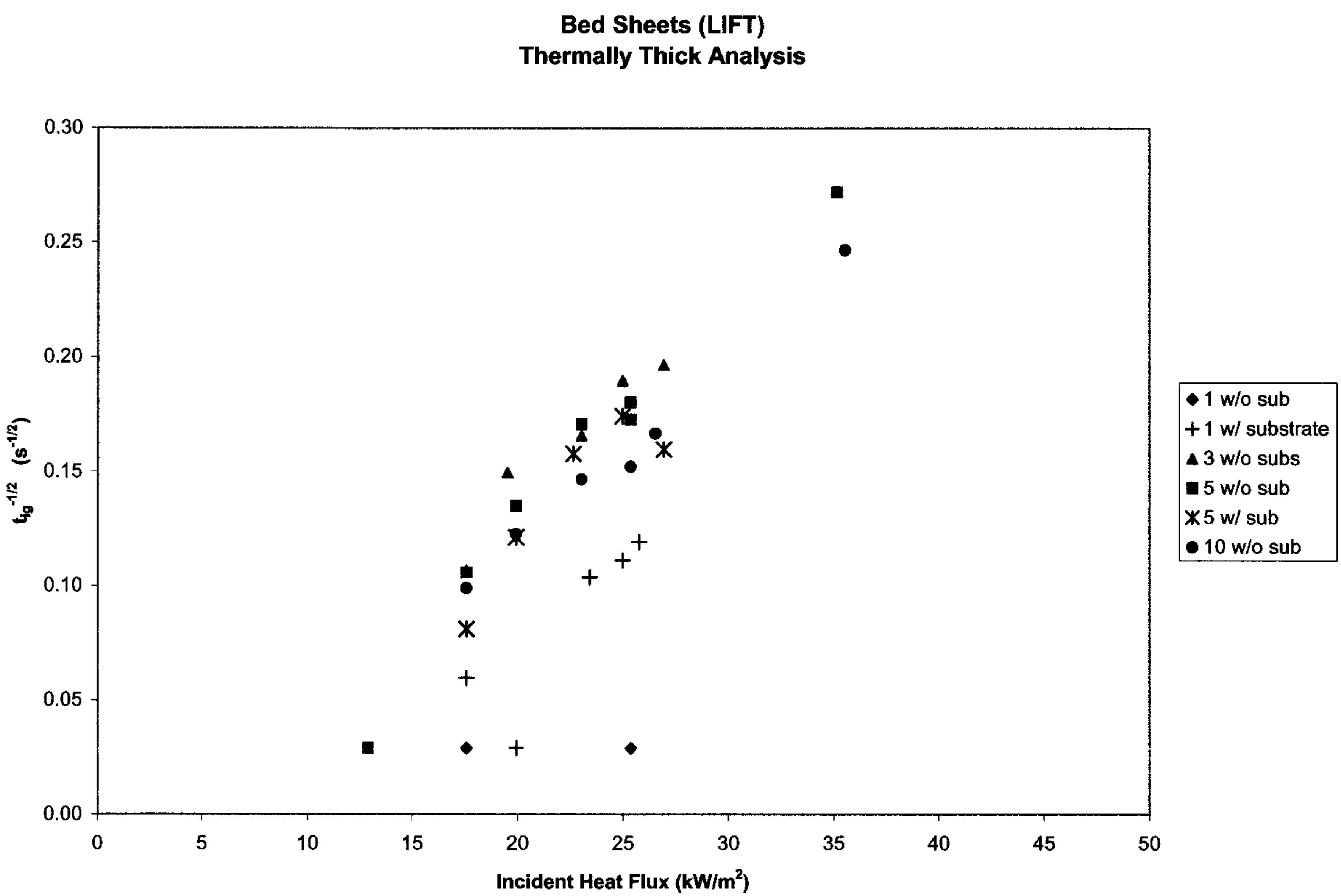


30.LIFTNewsprintThick

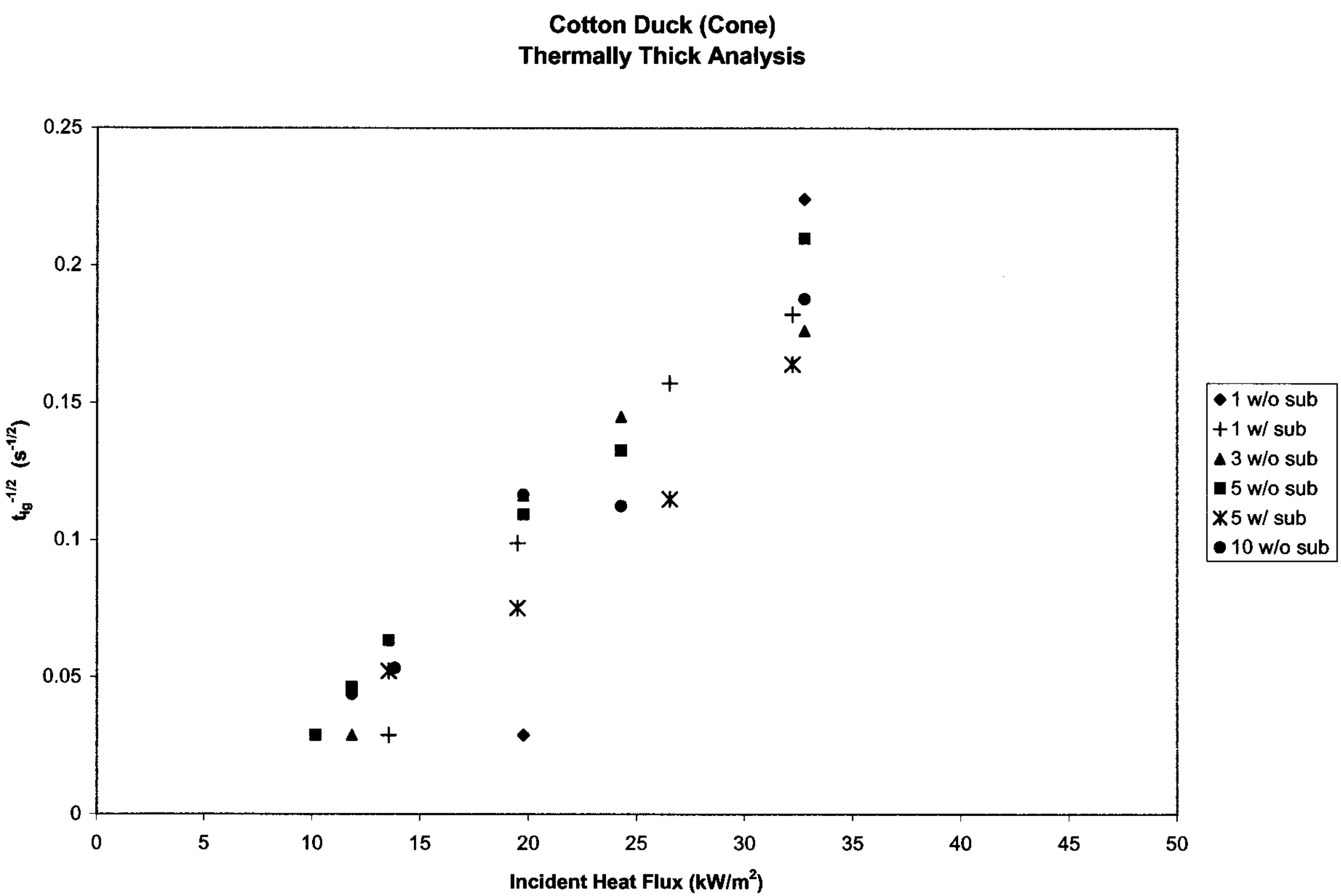
Bed Sheets (Cone)
Thermally Thick Analysis



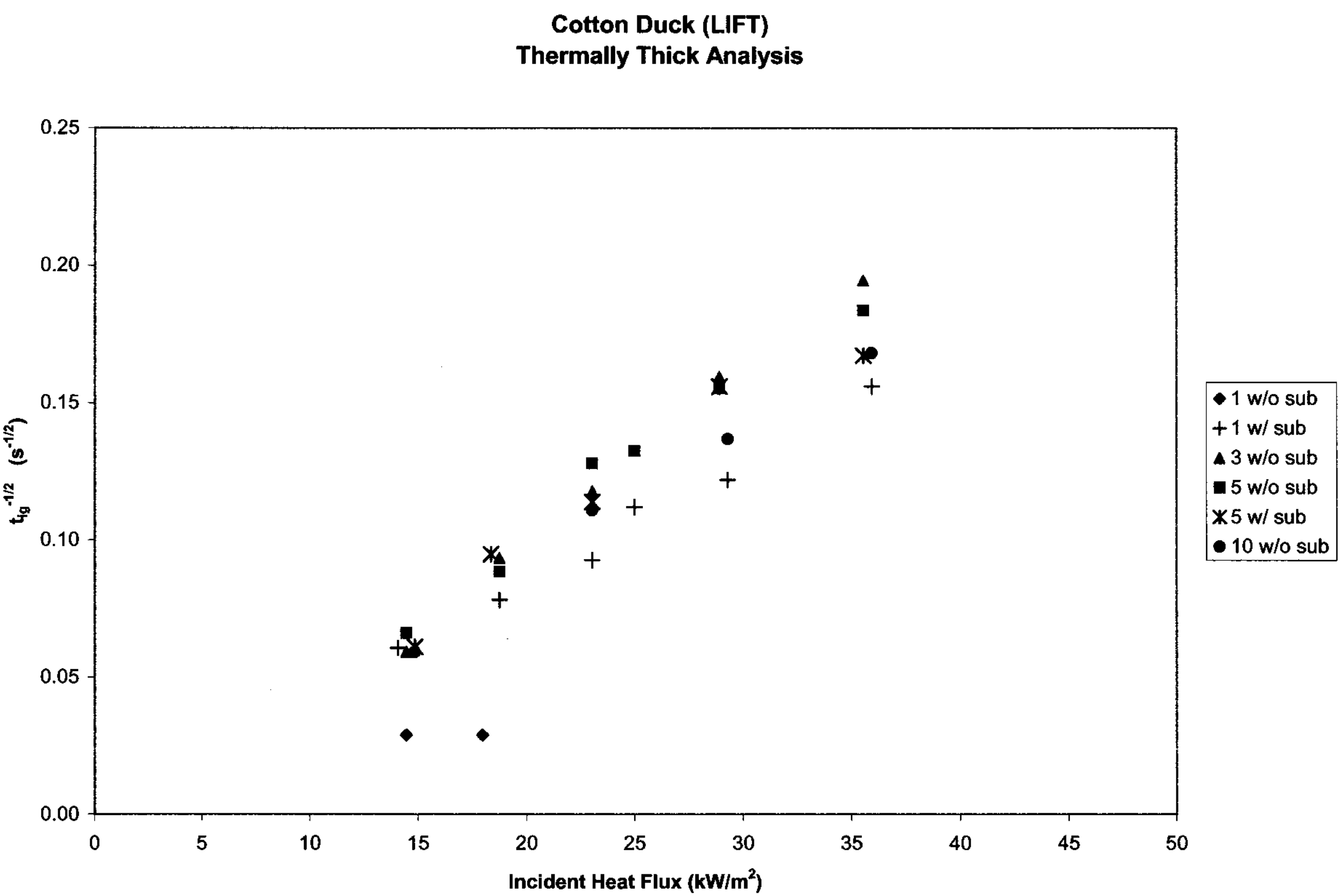
31.ConeBedsheetsThick



32.LIFTBedsheetsThick

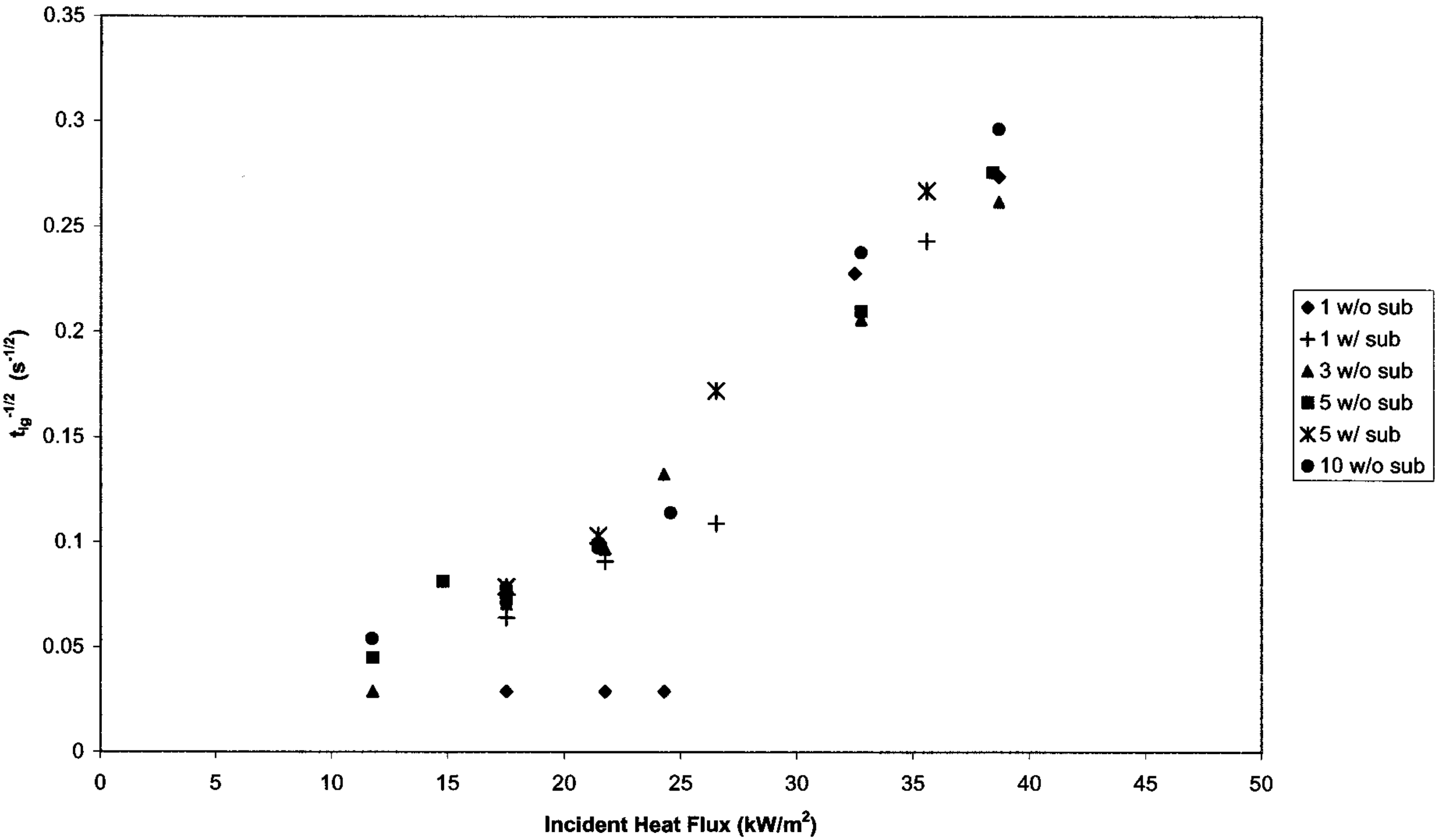


33.ConeDuckThick

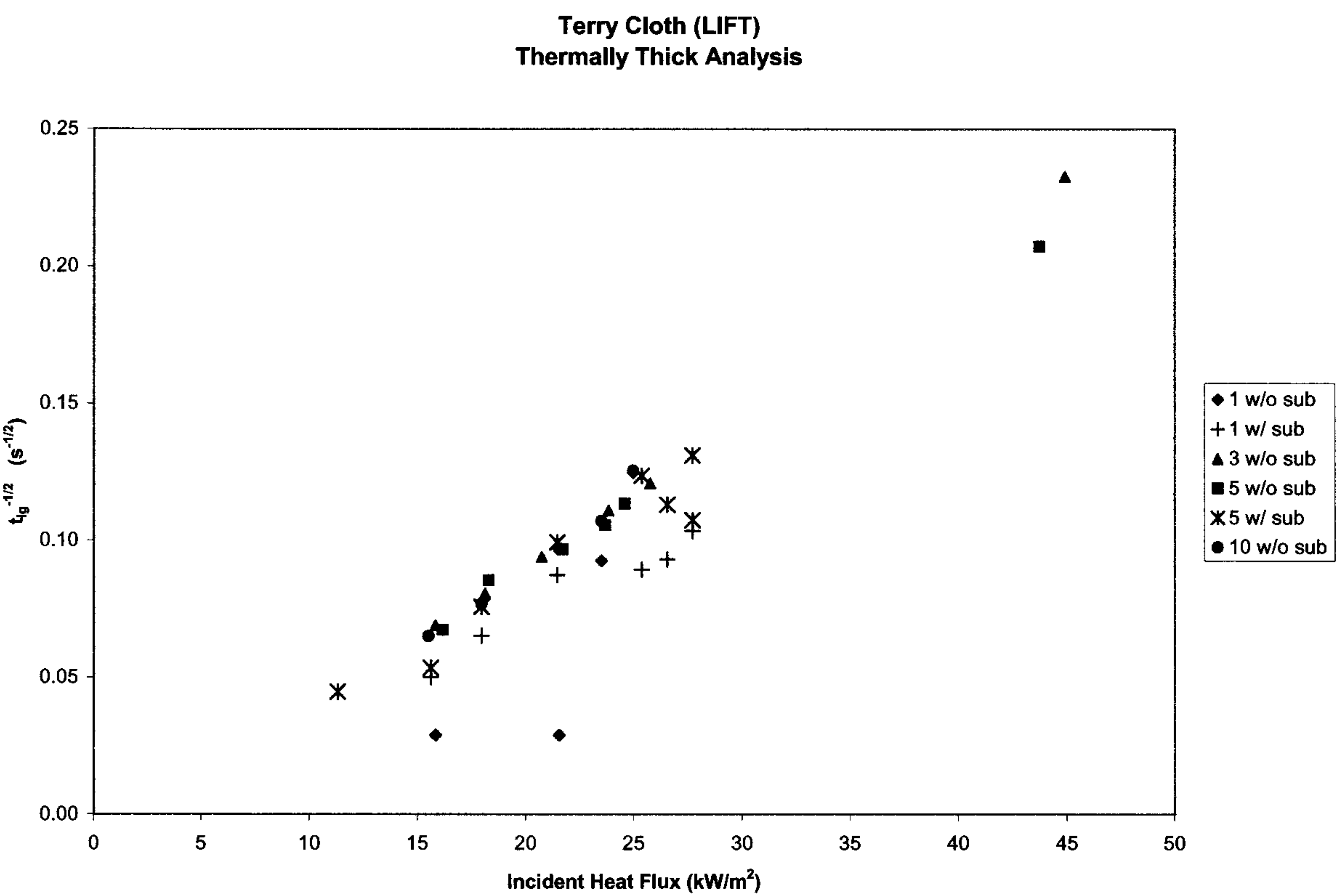


34.LIFTDuckThick

Terry Cloth (Cone)
Thermally Thick Analysis

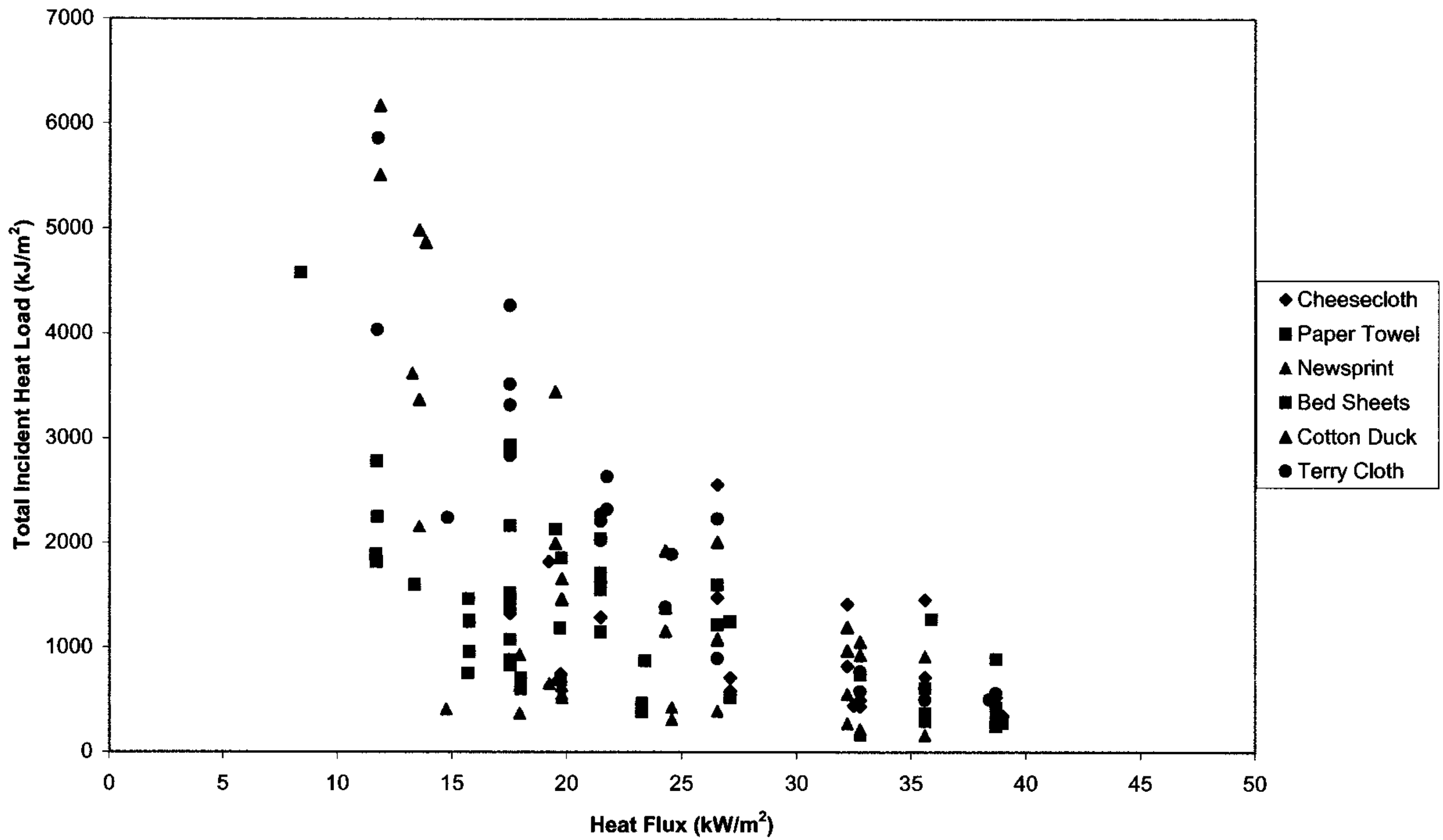


35.ConeTerryThick



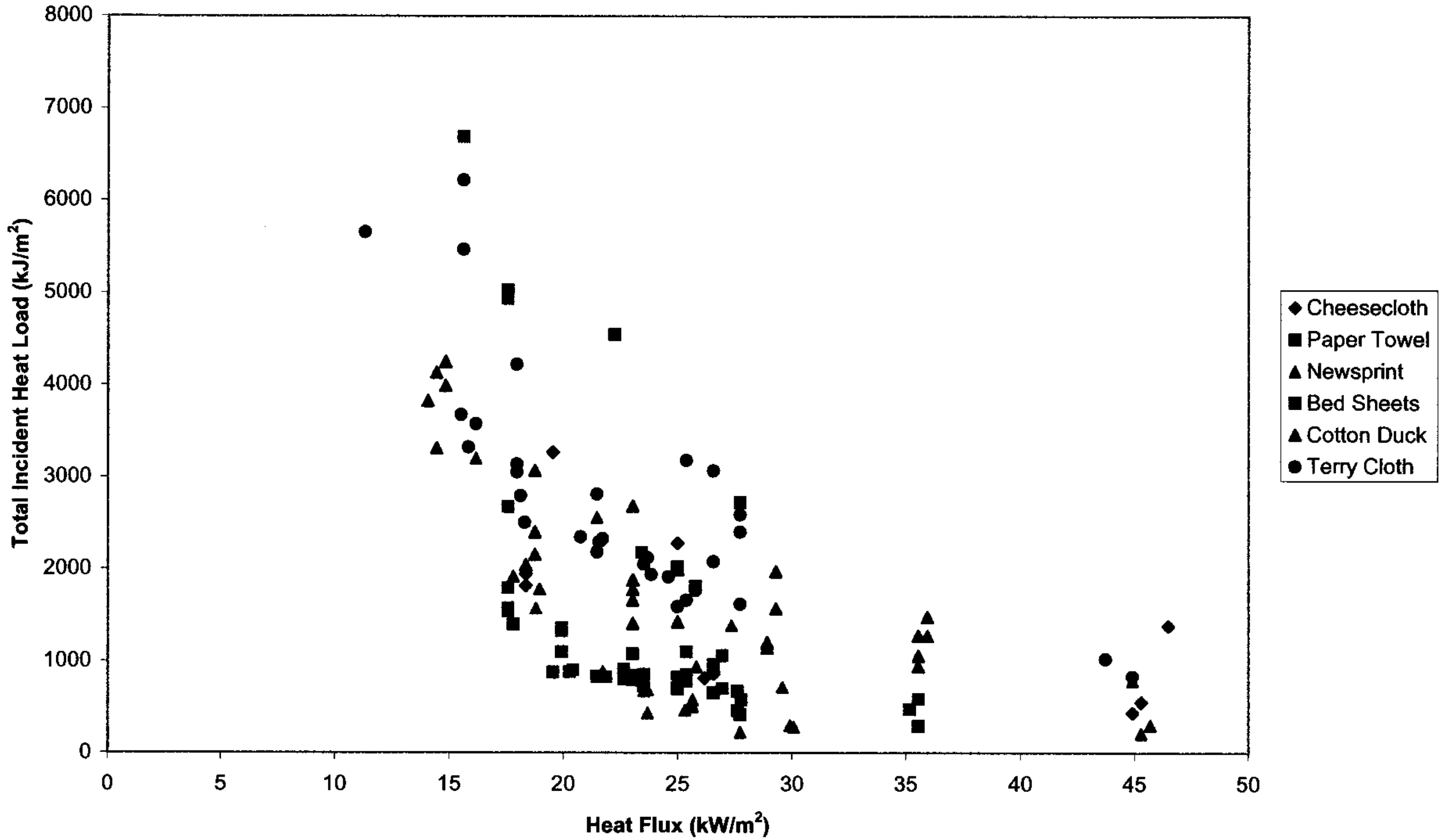
36.LIFTTerryThick

Incident Heat Load for Ignition
Cone Calorimeter



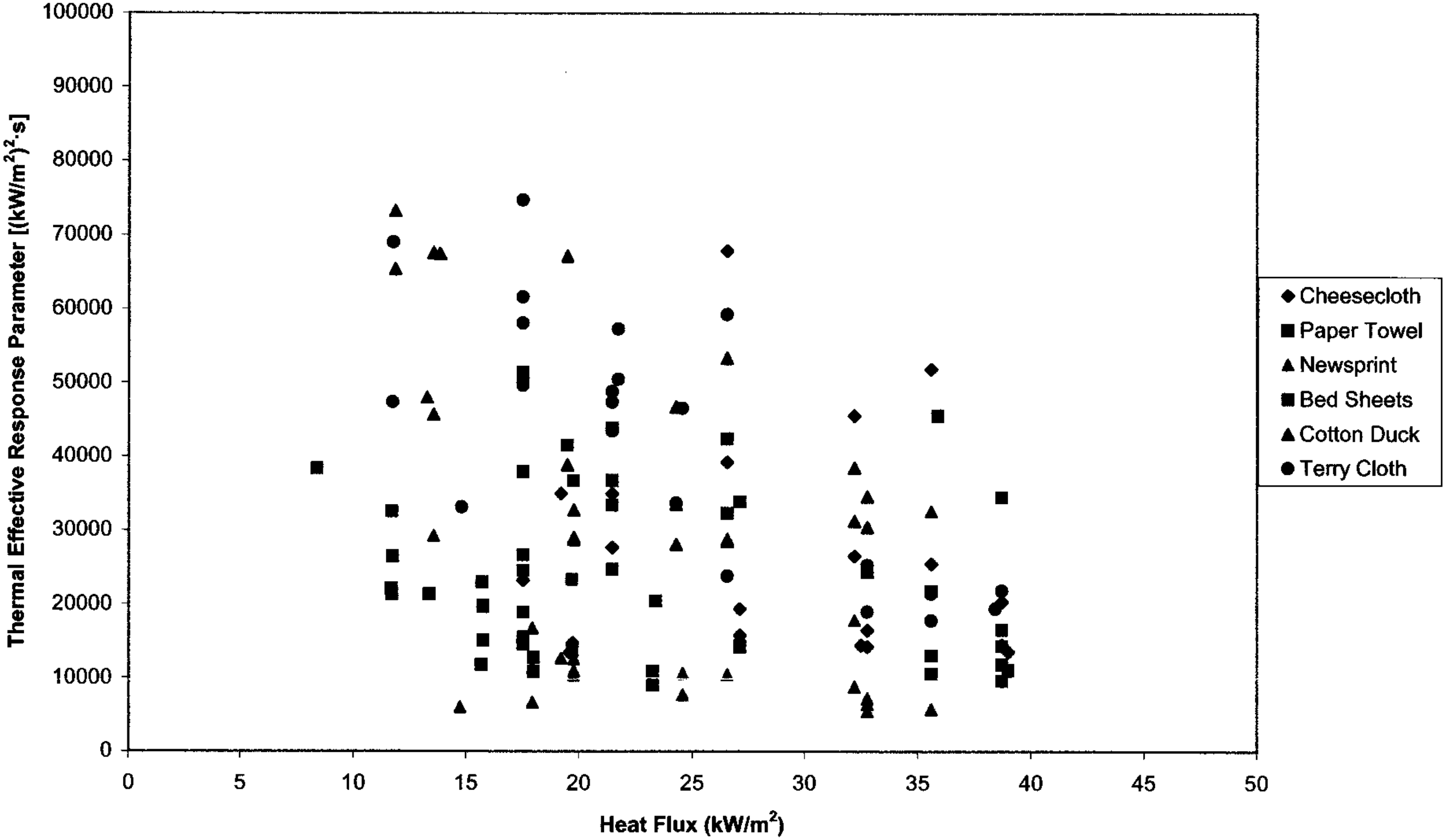
37.ConeHeatLoad

Incident Heat Load for Ignition
LIFT Apparatus

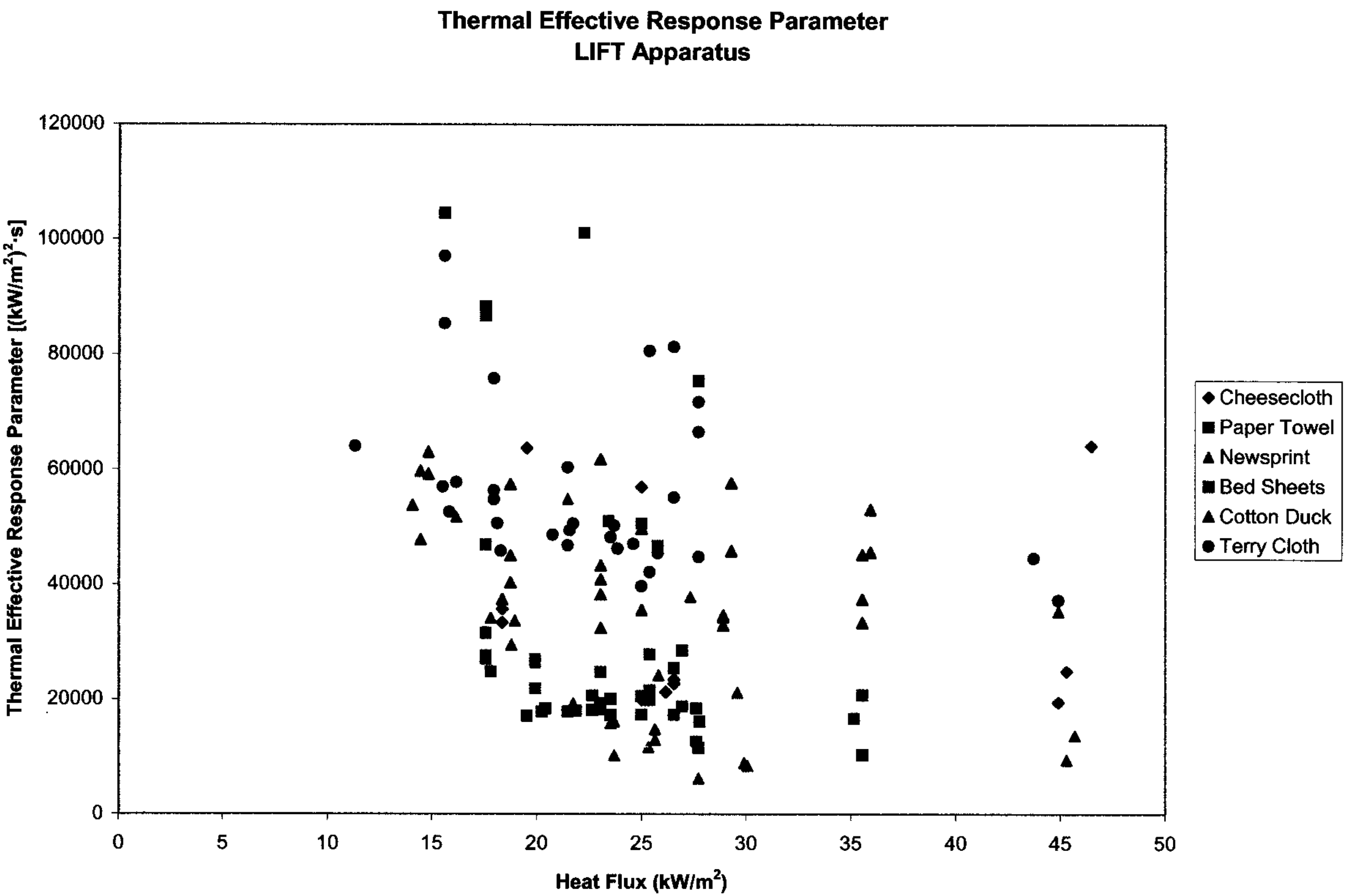


38.LIFTHeatLoad

Thermal Effective Response Parameter
Cone Calorimeter



39.ConeTERP


Thermal Effective Response Parameter
LIFT Apparatus
Thermal Effective Response Parameter [(kW/m²)²·s]
Heat Flux (kW/m²)
120000
100000
80000
60000
40000
20000
0
0
5
10
15
20
25
30
35
40
45
50
Cheesecloth
Paper Towel
Newsprint
Bed Sheets
Cotton Duck
Terry Cloth

40.LIFT TERP