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بیست و یکمین
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علوم حرارتی — انتقال حرارت و جرم با تغییر فاز

هیأت رئیسه نشست: دکتر عباس عباسی، دکتر تیمورتاش، دکتر سیروس آقانجفی

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بررسی تئوری و تجربی استفاده از دو نوع چگالنده تماس مستقیم و غیرمستقیم در آب‌شیرین‌کن HD

مجید محدمیرزایی[1]، محمد ضامن[2]، عباس عباسی[1]، مجید عمیدپور[1]
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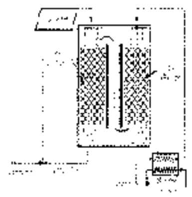

- بررسی تئوری و تجربی استفاده از دو نوع چگالنده تماس مستقیم و غیرمستقیم در آب‌شیرین‌کن HD
- بررسی معادلات حاکم بر فرایند دو نوع چگالنده: تماس مستقیم و غیرمستقیم
- بررسی اثرات دبی هوا، دبی آب شور و دبی آب گرم ورودی بر تولید آب شیرین و میزان مصرف انرژی
- با توجه به اینکه در استفاده از چگالنده تماس مستقیم دو حالت شامل استفاده از حرارت آب شور خروجی رطوبت‌زنی و حرارت آب شیرین خروجی از رطوبت‌زدایی(چگالنده) وجود دارد، به ترتیب دو پارامتر Q۱ و Q۲ برای انرژی مصرفی در هر حالت تعریف شده است و هدف در مشخص نمودن تغییرات این دو پارامتر و کاهش هر کدام می‌باشد.

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Numerical Simulation of Heat and Mass Transfer in Falling Film Absorption Generators

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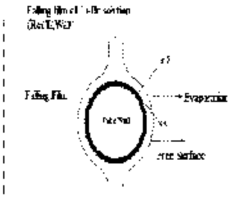

- computational fluid dynamics
- heat and mass transfer
- Li-Br falling film
- generator

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Correlation of Apparent Thermal Conductivity and Electrical Resistivity of Moist Thermal Insulation Materials

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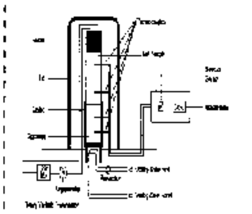

- An apparatus was developed for measuring apparent thermal conductivity of insulations
- An experimental relation between thermal conductivity and moisture content of EPS was obtained
- An experimental relation between electrical resistivity and moisture content of EPS was obtained
- A relation between apparent thermal conductivity and electrical resistivity of EPS was developed

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بررسی عددی تاثیر چرخش زیر لایه و فاصله الکترودها بر لایه نشانی سیلیکون در رآکتور PECVD

کامل میلانی شیروان[1]، امین بهزادمهر[2]، طاهره فنایی شیخ الاسلامی[3]، حسین آتشی[2]
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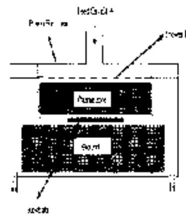

- معرفی رآکتور لایه نشانی(PECVD) و کاربرد این رآکتور در لایه نشانی سیلیسیوم در دما و فشار پایین
- تاثیر چرخش زیر لایه بر لایه نشانی سیلیسیوم، بر روی زیرلایه در رآکتور
- تاثیرفاصله الکترودها بر لایه نشانی سیلیسیوم، بر روی زیرلایه در رآکتور

[illegible]

مدل سازی انتقال حرارت تشعشع و هدایت در فرآیند انجماد به روش شبکه ای بولتزمن

آرمان معروفی[1]، سیروس آقانجفی[1]، حامد مظفری[1]
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- در این مقاله از روش شبکه ای بولتزمن (LBM) به منظور مدل سازی انتقال حرارت تشعشع و هدایت در فرآیند انجماد استفاده شده است.
- معادله حاکم شامل معادله انتقال حرارتی گذرا در فازهای مایع و جامد بوده و برای در نظر گرفتن تغییر فاز از فرمولاسیون انتالپی استفاده شده است.
- به منظور حاصل شدن صحت حل عددی، نتایج حاصل در حالت یک بعدی با حل تحلیلی مقایسه شده است. سپس در حالت دوبعدی با حل معادله انرژی، سرعت پیشروی مرز متحرک و توزیع دمای فازهای جامد و مایع تعیین شده و مورد بررسی قرار می گیرند.

Correlation of Apparent Thermal Conductivity and Electrical Resistivity of Moist Thermal Insulation Materials

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Abstract
The goal of the present study is to investigate the effect of moisture on apparent thermal conductivity and electrical resistivity of thermal insulation materials and finding their correlation. For this purpose, a set of experiments are conducted. In these experiments with changing the moisture content, thermal conductivity and electrical resistivity are measured. To measure the thermal conductivity, heat flow meter device is used and for measuring electrical resistivity, a simple electrical circuit is provided. Thermal conductivity and electrical resistivity curves according to moisture content are provided and consequently the correlation of apparent thermal conductivity and electrical resistivity for moist porous medium is obtained. Since available experimental methods of determination of apparent thermal conductivity for insulation materials are expensive and time-consuming and conducting them out of laboratory is not possible, by using the obtained correlation between two mentioned parameters, determination of apparent thermal conductivity of insulation materials by quick and affordable measurement of their electrical resistivity will be possible. Constants of the correlation for each material should be determined by experiments.

Keywords: apparent thermal conductivity, insulation materials, moisture, electrical resistivity

Introduction
Heat and mass transfer in moist porous media often occurs in nature and in engineering. Heat and mass transport properties are of primary significance in solving problems of this type. However, there are few quick and convenient means available for the measurement of these properties [1].
Methods for measuring apparent thermal conductivity are different according to type of material and the temperature at which the measurement is conducted [2]. To determine thermal conductivity of insulation materials, the following methods are available; guarded hot plate (GHP) [3] and heat flow meter (HFM) [4].
The mentioned methods need long time and special devices and instruments. Furthermore, conducting these experiments out of laboratory is not possible. Therefore, development of a cost-effective and ready to use method which can be conducted at installation location seems necessary.
Several researchers have shown that thermal conductivity of thermal insulation materials depends on numerous parameters [5, 6, 7, 8] such as moisture content and dry density. It is experimentally and theoretically shown that these parameters have an influence on the electrical resistivity. The fact that both thermal conductivity and electrical resistivity depend on the same parameters, indicates the possibility of their interrelation [9].
The objective of our research is the investigation (qualitatively and quantitatively) of the influence of moisture content on thermal conductivity and electrical resistivity of a thermal insulation material and the development of an expression that can be used to relate electrical resistivity to apparent thermal conductivity.

Theory
The mechanism of heat transfer in porous materials is complicated because of the irregularity of the microstructure. In these materials, heat is propagated by thermal conduction through the solid and fluid phase, radiation between solid particles and convection in the fluid phase [10].
As we know, Fourier's law is the fundamental law for conduction heat transfer. But it assumes that the heat transfers only by conduction, which is not correct in the case of the porous materials, because thermal radiation and sometimes convection highly contribute in heat transfer.
If we assume that heat transfer across the material is the result of conduction in the solid and fluid phases, radiation and convection, and different modes of heat transfer are not related to each other, then:

$$\overrightarrow{q_t} = \overrightarrow{q_{cd}} + \overrightarrow{q_{cv}} + \overrightarrow{q_{rad}} \quad (1)$$

Where q_t, $q_{cd}=q_{gs}+q_s$, q_{cv} and q_{rd} are respectively, the density of heat fluxes corresponding to the total conduction in the solid and gaseous phases and convection and radiation heat transfers.
If we also assume that, for each mode of heat transfer (noted as subscript i), the density of heat flux across a layer of a porous material between two infinite planar surfaces can be expressed as:

$$\overrightarrow{q_i} = -K_i.\vec{\nabla}T \quad (2)$$

Then we can easily derive the relation:

$$\overrightarrow{q_T} = -K^*.\vec{\nabla}T \quad (3)$$

with:

$$K^* = K_s + K_{gs} + K_{cv} + K_{rad} \quad (4)$$

Where K_s, K_{gs}, K_{cv}, K_{rad} are respectively, the solid conduction, gas conduction, and convective and radiative thermal conductivity. In fact K^* is apparent thermal conductivity for dry porous materials.

In a moist material, the density of heat flux is the sum of the Fourier's term and of a mass transfer term related to the heat transfer due to mass flows.

$$\vec{q} = \underbrace{-K^*\overrightarrow{\nabla T}}_{Fourier} + \underbrace{\overrightarrow{g_v}h_v + \overrightarrow{g_l}h_l}_{Mass\ Transfer} \quad (5)$$

The additional mass transfer term cause the problem of measuring K^*.

When liquid movement can be neglected (g_l=0) (Equation 6) and $\overrightarrow{g_v}(h_v) \ll K^*\vec{\nabla}T$ mass transfer term can be ignored. This is the case of impermeable materials for which vapor diffusion is very low, for instance, polystyrene.

$$\vec{q} = -K^*\vec{\nabla}T + \overrightarrow{g_v}h_v \quad (6)$$

We then have, in the case of one-dimensional flow, the classical [11]:

$$q \approx K^*\frac{dT}{dx} \quad (7)$$

Experimental Setup

Apparent Thermal Conductivity

A thermal conductivity measurement apparatus is modified to enable measurement of low thermal conductivities. In order to keep moisture in the specimen, a casing is designed and fabricated. The effect of moisture content on apparent thermal conductivity of thermal insulation materials is investigated by this apparatus. The determination of the apparent thermal conductivity by measuring the heat flux and temperature difference in two points of the specimen will be possible. Different parts of apparatus are as following:

1. An electric heater as the heating source
2. A clamp to fix specimen in apparatus
3. Calorimeter as heat sink
4. A lid which has a reflective internal surface to prevent heat dissipation
5. A flow meter for controlling the cooling water
6. Rotary selector switch for thermocouples
7. Four thermocouples (K type)
8. Rotary variable transformer to adjust electric current of heater
9. Thermocouple potentiometer

Reference sample is mounted on the specimen inside the apparatus. A casing has covered the moist specimen to keep the moisture. Generated heat flux by electric heater is transferred to calorimeter after passing through the reference sample and specimen. A lid is mounted on the specimens, calorimeter and heater. By reducing heat dissipation; lid helps the system to reach steady state sooner. The temperatures of two points on the centerline of reference sample and two points on the centerline of specimen are measured by means of four thermocouples. These thermocouples are connected to a rotary selector switch and a thermocouple potentiometer for measuring temperatures. Electric current which passes through the heater and consequently generated heat can be controlled by means of a rotary variable transformer. Also flow rate of cooling water which passes through the calorimeter is fixed on a special value by means of a flow meter.

The specimen used in this experiment is an expanded polystyrene (EPS). EPS is widely used for insulating the fridges and refrigerators. This cylindrical specimen of EPS has 25 mm diameter and 38 mm height. To prevent the moisture release, a casing from Polypropylene with 25 mm inside diameter and 2 mm thickness is designed and provided. Thermal conductivity of casing is equal to 0.20 [12]. Reference sample is a solid cylinder from polytetrafluoroethylene with 25 mm diameter and 64 mm height and thermal conductivity of 0.25 W/m.K [13].

The mass of specimen is measured before conditioning. The specimen is then moistened by keeping under the water. It is kept under the water till saturation. Then it is exposed to ambient and weights until reaches the required saturation. Afterward specimen with casing and reference sample are installed inside the apparatus and the experiment is started. The temperatures which are measured by thermocouples are recorded in different times after starting the experiment.

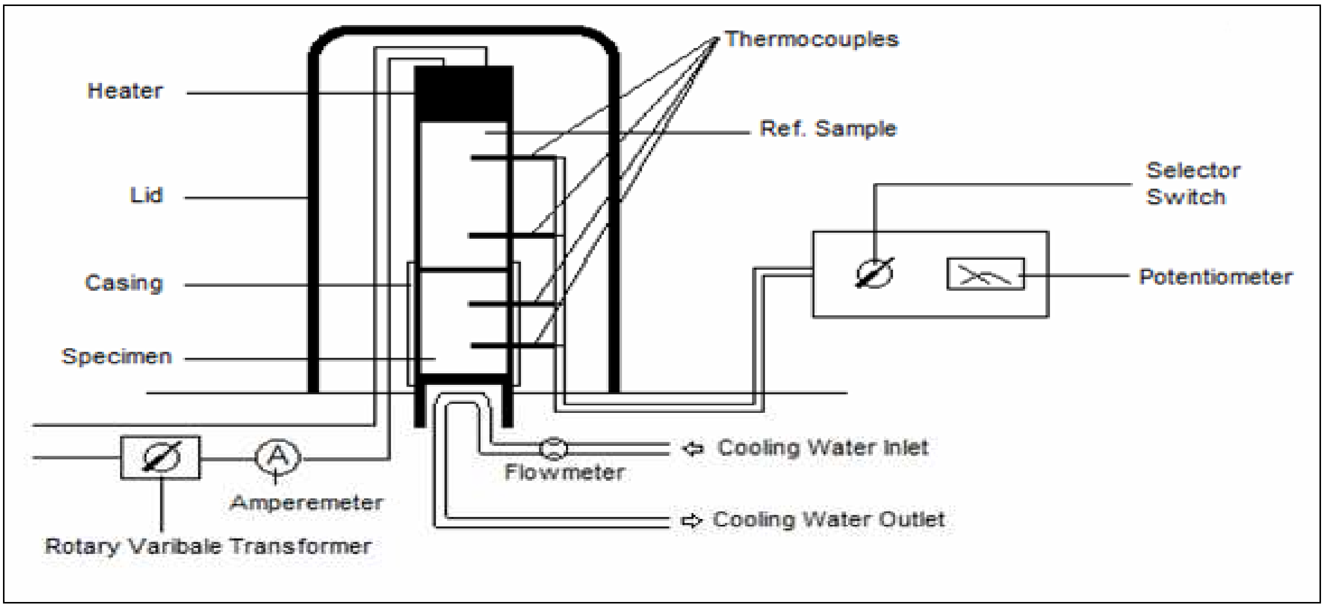

Figure 1: Apparent thermal conductivity measurement apparatus

Electrical Resistance

To measure the electrical resistance of the moist insulation material, a simple electrical circuit and an ohmmeter with measuring range to 20000 M.Ohm are used. The specimen is a cylinder with 25 mm diameter. Two nails are entered into the sides of the moist specimen and ohmmeter electrodes are in contact with these nails. The nails' tip have a distance of 10 mm from each other and just 2 mm of their tips are in contact with specimen and the remained are insulated with a layer of tape. The mass and electrical resistance of saturated specimen which is in contact with ambient is measured in different times.

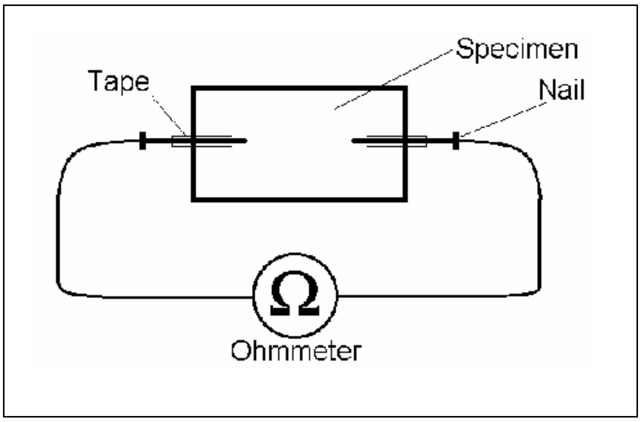

Figure 2: Electrical Resistance Experiment Setup

Analysis

Apparent Thermal Conductivity

The apparent conductivity is calculated according to Fourier's law when the system reaches steady-state. Because of one dimensional heat transfer in steady-state condition, the heat flux which passes through the reference sample will be equal to the passed heat flux through experiment specimen and casing. By considering the thermal conductivity of polytetrafluoroethylene as a known parameter, then:

$$q = -K_{PTFE} A \frac{dT_{PTFE}}{dy_{PTFE}} \quad (8)$$

The calculated heat flux by Equation 8 passes through the casing and insulation material. By using thermal resistance method, the thermal resistance of specimen and casing will be as following:

$$R_{EPS} = \frac{dy_{EPS}}{K_{EPS} A} \quad (9)$$

$$R_{PP} = \frac{dy_{PP}}{K_{PP} A_{PP}} \quad (10)$$

Resistances are parallel so the equivalent resistance will be defined as below:

$$\frac{1}{R_{eq}} = \frac{1}{R_{pp}} + \frac{1}{R_{EPS}} = \frac{K_{PP} A_{PP}}{dy_{PP}} + \frac{K_{EPS} A}{dy_{EPS}} \quad (11)$$

$$\xrightarrow{dy_{PP}=dy_{EPS}} R_{eq} = \frac{dy_{EPS}}{K_{PP} A_{PP} + K_{EPS} A} \quad (12)$$

Because of the same heat fluxes through the reference sample and specimen with casing, thermal conductivity can be defined as:

$$q = \frac{dT_{EPS}}{R_{eq}} = \frac{dT_{EPS}}{dy_{EPS}} (K_{PP} A_{PP} + K_{EPS} A) \quad (13)$$

$$K_{EPS} = K_{PTFE} \frac{dy_{EPS}}{dy_{PTFE}} \frac{dT_{PTFE}}{dT_{EPS}} + K_{PP} \frac{A_{PP}}{A} \quad (14)$$

Because of high thermal resistance EPS, reaching the steady state for this experiment will need a long time. On the other hand, if the experiment become so long, moisture distribution in specimen will change that is not desirable. To prevent this problem, thermocouples temperatures are recorded until the system reaches near the steady-state condition. If we fit a curve on the obtained data for dT_{PTFE}/dT_{EPS} versus time, when time tends to infinity, dT_{PTFE}/dT_{EPS} approaches a value which is used to determine K_{EPS} (Figure 3). These curves which are fitted by MATLAB Curve Fitting Toolbox are of the following form:

$$y = ax^b + c \quad (15)$$

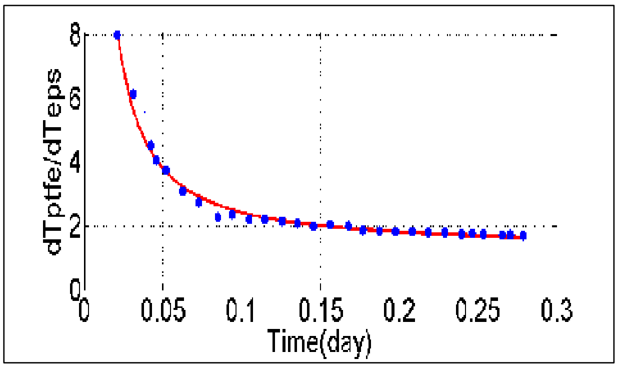

Figure 3:Temperature Difference Ratio vs. Time for a specimen of 24% saturation

Electrical Resistivity

Electrical resistivity can be calculated by using measured electrical resistance as below:

$$\rho = Re \frac{A}{l} \quad (16)$$

Results and Discussion

The measured apparent thermal conductivity of dry insulation specimen used in the present study is equal to 0.037 W/m.K. To better investigate the effect of moisture content, other results are reported as a ratio of thermal conductivity of moist specimen to thermal conductivity of dry insulation in Figure 4. This figure shows that moisture absorption can increase the thermal conductivity of expanded polystyrene up to 2.5 times. According to Figures 4, a linear trend line fits the diagram best. The equation of this fitted trend line is as:

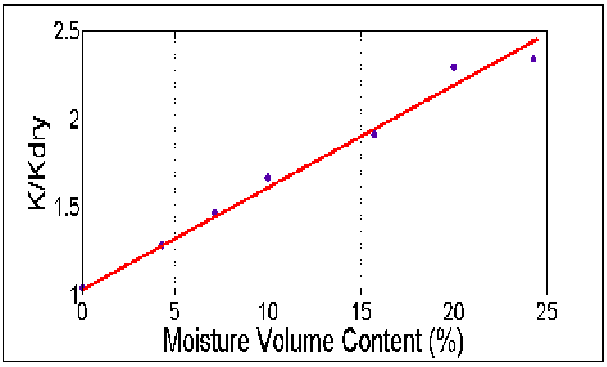

Figure 4:Apparent thermal conductivity ratio vs. moisture volume content for moist expanded polystyrene

$K/Kdry = 0.05819m + 1.026$ (17)

Figure 5 shows the results for the same material which is used for validation in this study.

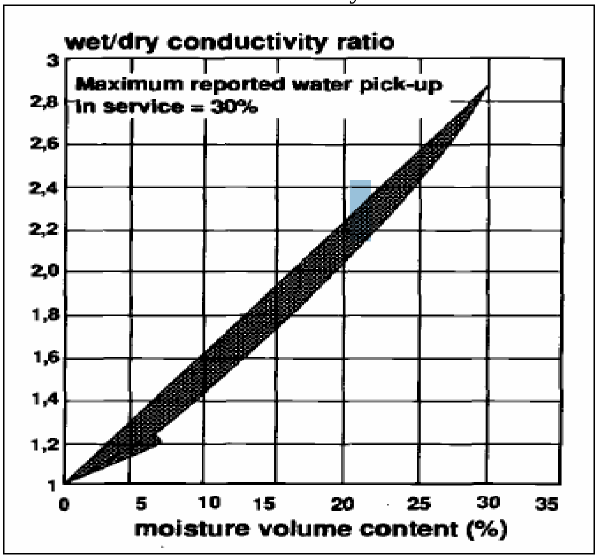

Figure 5: Apparent thermal conductivity ratio vs. moisture volume content for expanded polystyrene [11]

Figure 6 shows the electrical resistivity vs. moisture content for EPS. According to the obtained results,an exponential function fits the diagram best. The equation of fitted curve is as follow:

$\rho = 1.077E5m^{-3.657} + 0.859$ (18)

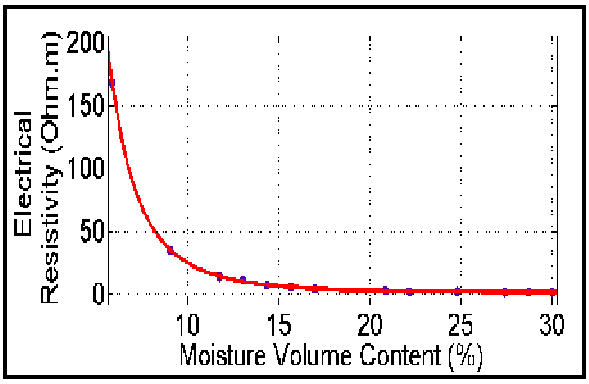

Figure 6: Electrical resistivity vs. volume moisture content for expanded polystyrene

By finding the reverse of mentioned function, moisture content can be found from electrical resistivity.

$$\ln\left(\frac{\rho - 0.859}{1.077E5}\right) = -3.657m$$ (19)

$$\rightarrow m = 3.168\mathrm{n}(\rho - .859)$$

If we put the moisture content in Equation 17 with the obtained value in Equation 19, we have:

$K/Kdry = 0.213ln(\rho - .859) + 1.026$ (20)

Equation 20 can be used for determination of apparent thermal conductivity by measurement of electrical resistivity.

Conclusions

Available methods for measuring apparent thermal conductivity of insulation materials are expensive and time-consuming and conducting them out of laboratory is not possible. In the present paper, a method was developed which can determine the thermal conductivity by measuring electrical resistance of the insulation. This simple method does not need a long time for measurement and can be conducted out of laboratory.

List of Symbols

A	Area
EPS	Expanded polystyrene
eq	Equivalent
cd	Conduction
cv	Convection
g	Density of moisture flow
gs	Gas
h	Enthalpy
K	Thermal conductivity
l	Length
m	Moisture Content
PP	Polypropylene
PTFE	Polytetrafluoroethylene
q	Heat
R	Thermal resistance
rad	Radiation
Re	Electrical resistance
s	Solid
T	Temperature
t	Total
v	Vapor
y	Height

Greek Symbols

ρ	Electrical resistivity

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