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Novel and Simple Formulae to Calculate Air Molecular-Transport Properties of Momentum and Heat Transfer.

By

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خلاصة – يعرض هذا البحث ثلاثا من الصيغ الرياضية لحساب كل من اللزوجة المطلقة واللزوجة الكينماتيكية ومعامل التوصيل الحرارى للهواء بمعلومية درجة حرارة الهواء وضغطه. والصيغ الثلاث مستنبطة بالطرق الرياضية العددية من واقع المعلومات المتوافرة بالمراجع عن صفات الهواء الطبيعية .

وتتميز هذه الصيغ باتساع مدى تطبيقها حيث يمكن تطبيقها حتى درجة حرارة مقدارها ٢٥٠٠ درجة مطلقة وتحت ضغوط لا تتعدى ١٠ ضغط جو . كما أن أقصى حيود للقيم المحسوبة عن القيم المماثلة المتوافرة فى المراجع هو ± ٣٪ ، يضاف الى ذلك أنها تعطى صفة الهواء الطبيعية المطلوبة فى خطوة حسابية واحدة فى سهولة ويسر . والفائدة العظمى لتلك الصيغ تكمن فى استبدال اللزوجة ومعامل التوصيل الحرارى للهواء بدرجة حرارة الهواء وضغطه مما يسهل كثيرا جميع الحسابات المتصلة بالهواء وخاصة حسابات انتقال كمية الحركة وانتقال الحرارة حيث لم تعد هناك حاجة للرجوع للمراجع عند كل ظروف تشغيل لايجاد صفات الهواء الطبيعية والتى كانت وحتى الآن تمثل مشقة كبيرة للباحثين فى هذه المجالات .

ABSTRACT - In this paper three novel and simple formulae are deduced to calculate the dynamic viscosity, the kinematic viscosity and thermal conductivity of air on knowing air temperature and pressure.

These formulae can be applied under a wide range of working conditions. They can be used at any temperature (up to 2500 °K) and at pressures below 10 atmospheres.

Formula (3) gives the dynamic viscosity of air while formula (6) gives its thermal conductivity on knowing air temperature. Formula (5) gives the kinematic viscosity of air as a function of air temperature and pressure.

Each formula gives the required property in one step calculation with an excellent accuracy as only ± 3% maximum deviation from the available data in the literature is noted over that wide range of working conditions.

From these formulae momentum and heat-transfer calculations which need the knowldge of viscosity and thermal conductivity of air can now be done on knowing air temperature and pressure without referring to the literature to get these physical properties. In this way a great simplicity and availability in air calculations is realized.

Introduction

For any fluid the usual method for the dynamic viscosity (μ) and thermal conductivity (K) determination is to measure them experimentally or to get them from the literature under the specified working conditions [1-7].

The kinematic viscosity (ν) which equals to ($\frac{\mu}{\rho}$) where (ρ) is the fluid density can be determined from the dynamic viscosity and density of the fluid.

Momentum and heat transfer calculations require the knowldge of the dynamic viscosity (μ) or the kinematic viscosity (ν) and thermal conductivity (K) of the working fluid in addition to some measurable parameters such as flow velocity (U) and the equivalent diameter of the duct (D). For example condition of flow is determined by the value of the Reynolds number (Re) where;

$$Re = \frac{DU}{\nu} \qquad \ldots (1)$$

Also the convective heat transfer coefficient (h) is usually determined through

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empirical correlations e.g. for air

$$Nu = \left(\frac{hD}{k}\right) = 0.018 \ Re^{0.8} \qquad \ldots (2)$$

Here the reference temperature is the mean temperature of air (T) and the reference dimension is the equivalent diameter of the duct (D). As shown in equation (1) the kinematic viscosity must be determined before calculating the Reynolds number while equation (2) asks for the kinematic viscosity and thermal conductivity in order to calculate the convective heat transfer coefficient.

Suppose that a series of momentum and heat transfer experiments are to be conducted on air. Each experiment asks for the above mentioned air physical properties under its specific working conditions which is a tedious and time consuming operation. That is why the present paper is devoted to simplify such a work by deducing simple and accurate correlations to calculate viscosity and thermal conductivity of air from air temperature and pressure.

Results and discussion

The following simple empirical formula was deduced to calculate the dynamic viscosity of air (μ) in terms of temperature as,

$$\mu = (4.6 \times 10^{-7})\ T^{0.65} \quad kg/m.s \qquad \ldots (3)$$

where T = air temperature, °K.

This formula was derived by plotting [dynamic viscosity (μ)- temperature (T)] data for air from the literature [1-7] on logarithmic paper. Visual inspection shows that (μ-T) data can be represented by :

$$\mu = a\ T^{n}$$

Determination of the arbitrary constants (a) and (n) was done by the method of averages [8] which gives $a = 4.6 \times 10^{-7}$ and $n = 0.65$.

The dependence of dynamic gas viscosity on pressure up to 10 atmospheres may be neglected [5,6].

Formula (3) can be used to calculate the dynamic viscosity of air instead of the more complicated formule present in the literature [1]. The accuracy of that formula to represent the available data [1-7] lies within ± 2% as shown in table (1) .

Air density is given by $\rho = \frac{P\,M}{R\,T}$ where,
P = air pressure; atm, T = air temperature °K, M = average molecular weight of air (= 29.0 gm/mol.), and R = molar gas constant (0.082 atm. lit/°K. mol.). So,

$$\rho = 353.66\ \frac{P}{T} \quad gm/lit\ (or\ kg/m^3) \qquad \ldots (4)$$

The kinematic viscosity (ν) is given by $\nu = \frac{\mu}{\rho}$. So, on substitution from expressions (3) and (4) we get

$$\nu = \left(\frac{1.3 \times 10^{-9}}{P}\right) T^{1.65} \quad m^2/s \qquad \ldots (5)$$

where T air temperature °K
P air pressure atm.

Formula (5) gives the kinematic viscosity of air at any temperature and at pressures below 10 atm. This formula must be examined for pressures greater than 10 atm.

Table (1) shows a comparison between values of the kinematic viscosity of air from the literature [1-7] and those calculated by formula (1). Table (1) shows

Table (1) Properties of air (S.I. units) from the literature [1-7] (μ_l, ν_l) against values of the same properties (μ_c, ν_c) calculated from the deduced empirical formule (3,5)

Air temp. °K	300	350	400	600	900	1200	1500	1800	2000	2200
$\mu_l \times 10^5$	1.85	2.08	2.29	3.01	3.89	4.69	5.40	6.07	6.50	6.93
$\mu_c \times 10^5$	1.87	2.07	2.26	2.94	3.83	4.62	5.34	6.01	6.43	6.84
μ_l/μ_c	1.01	0.99	0.99	0.98	0.98	0.98	0.99	0.99	1.01	1.01
$\nu_l \times 10^5$	1.57	2.08	2.59	5.13	9.93	1.59	22.9	30.8	36.9	43.3
$\nu_c \times 10^5$	1.59	2.05	2.57	4.99	9.74	1.57	22.6	30.6	36.4	42.6
ν_l/ν_c	1.01	1.01	0.99	0.97	0.98	0.99	0.99	0.99	1.01	1.02

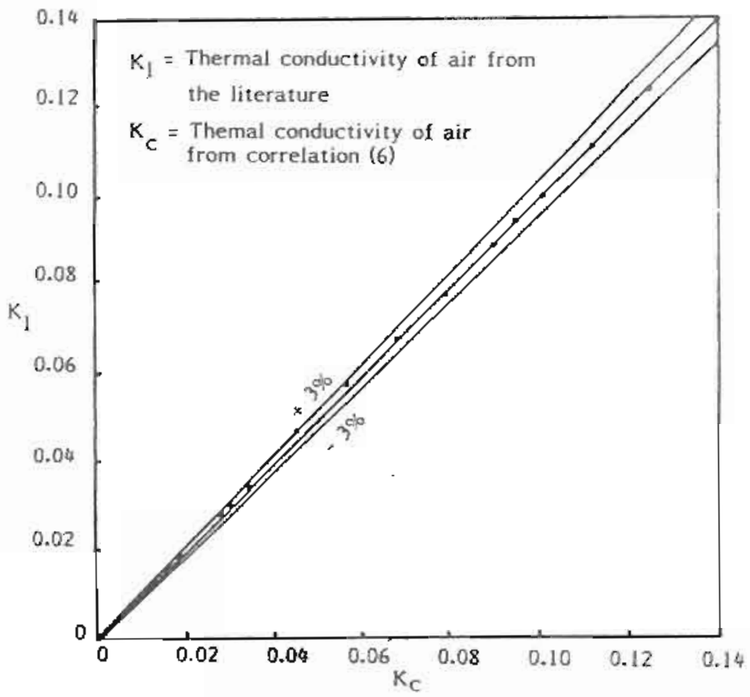

Figure (1) Validity of correlation
$K = 0.01\ [\ 1+(5.75\times10^{-3}).T\ ]$

that the accuracy of correlation (5) lies within ± 3% .

Drawing thermal conductivity (K) versus temperature (T) on linear paper, a straight line with a slope and intercept of 5.75×10^{-5} and 0.01 respectively is obtained. Hence the following formula can represent thermal conductivity (K) - temperature (T) data for air;

$$K = 0.01 [1 + (5.75 \times 10^{-3}) . T] \quad ... (6)$$

The accuracy of this correlation to represent (K-T) data available [1-7] lies within ± 3% as shown in figure (1).

These correlations are mainly deduced to facilitate momentum and heat transfer calculations concerning air. Two examples are taken here, condition of flow of any fluid is determined by the value of the Reynolds number given by formula (1). For air Reynolds number (Re) can be written as,

$$Re = (7.7 \times 10^{8}) D. U. P.T^{-1.65} \quad ... (7)$$

This formula is deduced by substituting the value of the kinematic viscosity from formula (4) on the Reynolds number formula (1).

Also for air the convective heat transfer coefficient can be calculated directly from

$$h = 1.8 \times 10^{-4} \ Re^{0.8} \left[\frac{(1 + 5.75 \times 10^{-3} \ T)}{D} \right] \quad ... (8)$$

which is deduced from equations (2) and (6).

Correlations (7) and (8) shows that the Reynolds number and the convective heat transfer coefficient for air flow in a certain duct can be calculated on knowing the equivalent diameter of the duct (D) and measuring air velocity (U), air pressure (P) and temperature (T) without referring to the literature for any more data which means a great simplicity and availability in air calculations.

Similarly other air calculations which ask for its viscosity and thermal conductivity can be simplified and air temperature and pressure replace these properities .

Example: Air flows through an 85-mm diameter duct that is 5 m long.

The average air velocity is 3m/s. Estimate the heat transfer coefficient for an average air temperature of 95°C [9]

Solution by the deduced formulae gives;

$$Re = (7.7 \times 10^{8}) (0.085) (3) (1) (368)^{-1.65} = 11,405 \quad \text{and hence} ,$$

$$h = (1.8 \times 10^{-4}) (11405)^{0.8} \left[\frac{1 + (5.75 \times 10^{-3}) (368)}{(0.085)} \right] = 11.66 \ W/m^2 . {}^\circ K$$

Classical solution [9] gives; $h' = 11.63 \ W/m^2 . {}^\circ K$

So, $\frac{h}{h'} = 1.003$ which clear the simplicity and accuracy of the deduced empirical correlations .

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