（様式課程博士３）

学 位 論 文 の 要 旨

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学位論文題目	Studies on Thermal Characteristics of Open-Cellular Porous Burners （オープンセル状多孔質バーナーの伝熱特性に関する研究）		

The objective of the present dissertation is to attain the fundamental understandings of solution methods for solving the radiative transfer equation and combustion phenomena of porous burner related to radiative emission characteristics of open-cellular porous materials. In order to meet this objective, the dissertation is arranged into three steps. Step one conducts numerical computation of radiation emission properties of the open-cellular porous materials at high temperature. In step two, experimental determinations and numerical analysis of combustion phenomena and radiation emission characteristics for open-cellular porous burners are presented. Finally, enhancements of the combustion in open-cellular porous burner on account of radiation recirculation are reported in step three.

Two numerical studies in step one are as follows. The first numerical study aimed to improve accuracy of P_1 approximation method in the calculation of the radiative transfer equation. In this method, the second order Legendre expansion coefficient of the radiation intensity Φ_2 appearing in P_1 equations was approximated by the zeroth order one Φ_0 in the form of $\Phi_2 = (K/2)\Phi_0$. Here, K denotes a correction factor and was determined so as to reproduce the hemispherical emittances of isothermal, gray, Henyey-Greenstein's scattering media bounded by a black surface. A value of K thus determined changes variously with the optical thickness τ_0 in the range of τ_0 less than about five, but converges asymptotically to some constant value denoted by K_∞. An accurate rational approximation to K_∞ is derived. Therefore, a modification of P_1 equations using an asymptotic correction factor K_∞ was called an improved P_1 approximation. The validity of the improved P_1 equations was examined in some pure radiation problems. For the second numerical study, spectral or total normal emittances of an isothermal, plane-parallel, open-cellular porous plate placed on an opaque diffuse substrate were investigated by solving the equation of transfer, and obtained results were compared with available experimental data. The extinction coefficient, the albedo and the asymmetry factor of a scattering phase function appearing in the equation of transfer as parameters were predicted by Kamiuto's radiative property model whose input parameters include the porosity, the number of pores per inch

（注）和文 2,000 字又は英文 800 語以内　　続紙　有■　無□

(*PPI*) and reflectivity of the solid material. A comparison between theoretical predictions and available spectral or total emittance data for three kinds of open-cellular porous plate, consisting of cordierite, Ni–Cr open-cell foams for total normal emittances and alumino-silicate for spectral normal case, reported in literature shows acceptable agreements within experimental uncertainty, and thus a theoretical approach of the radiative transfer equation incorporating Kamiuto's model is effective in predicting the emission characteristics of open-cellular porous plates.

In step two, open-cellular porous burners were employed experimentally and numerically to investigate the radiation emission characteristics of the burner. For the experiment, three kinds of Ni-Cr open-cellular porous material were examined and a two-color radiometry was used to observe the radiant energy from the porous burner. The surface temperature of porous burner was also measured. The numerical model of combustion phenomena was predicted on the basis of one-dimensional, lean premixed methane-air combustion without assuming a flame position, and a single-step Arrhenius rate expression was modeled for the kinetic mechanism of the combustion model. Predicted results of the forward radiative heat flux and the burner surface temperature were favorably compared with experimental data: satisfactory agreement between theory and experiment was obtained, and thereby the validity of the present theoretical model for predicting the radiation from a porous burner was confirmed. The flame of the porous burner could occur within or at the surface of the porous burner depending on *Re*. Moreover, it is found that there is only a little difference between predicted results of Barkstrom's method and these of the P_1 approximation.

Step three was studied experimentally and theoretically to improve the combustion of open-cellular porous burner by concerning the heat recirculation emphasized on a radiation mode of heat transfer. The burner of this type consisted of three sections (layers), the first and third layers are open-cellular porous plates whereas the second layer is free space, as defined as a multi-layered porous burner. The open-cellular material, experimental procedure and theoretical method for solving the equation of transfer were operated similar to those of a single-layered porous burner in step two. The combustion were stabilized within free space (second layer) acted as a flame holder, and the flame shifted from the near upper surface of the first layer toward the center of the second layer as *Re* increases. With comparing between the burners in step two and three, the flammability limits (blow-off and flash back) and the values of the dimensionless forward radiative heat flux in a multi-layered porous burner were lower than those of a single-layered porous burner. Agreement between the prediction based on Barkstrom's method and theory based on P_1 equations was satisfactory.

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学位論文審査結果の要旨

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論　文　題　目	Studies on Thermal Characteristics of Open-Cellular Porous Burners (オープンセル状多孔質バーナーの伝熱特性に関する研究)		
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審査結果の要旨（1000 字以内）

多孔質バーナーは従来のバーナーと比較し、希薄燃焼、広範な出力条件での運転が可能、コンパクト、CO や NOx 等の汚染物質の排出が少ないなどの多くの利点を有している。多孔質は構造上、ハニカム状、オープンセル状、クローズドセル状に分類されるが、本論文は、オープンセル状多孔質バーナーの伝熱特性の解明を目的とし、3 つに分けて研究を行っている。

まず、高温における等温条件下のオープンセル状多孔質のふく射特性を理論解析している。Kamiuto のふく射物性モデルを使用することにより、ふく射輸送方程式の計算における従来の P_1 近似法の精度改善を行っている。改良 P_1 近似法の解は既報の実験データおよび厳密解と比較され、良好な一致を示した。これにより、上記モデルの使用がオープンセル状多孔質体のふく射特性を予測する上で効果的であることを検証している。

次に、多孔質バーナーの伝熱特性に関する実験および数値解析を行っている。実験には 3 種類の多孔質を用いて、それぞれのふく射エネルギーおよびバーナー表面温度を測定している。燃焼現象は希薄予混合のメタン－空気燃焼であり、燃焼数値モデルには１次元、１段総括反応が使用されている。数値解析による結果は実験データとよく一致し、多孔質バーナーからのふく射を予測する本理論モデルの妥当性を確認している。

最後に、単層バーナーを多層化することにより排熱の熱再循環を図り、燃焼特性の改善を行っている。具体的には多孔質を 2 層使用した多層オープンセル状多孔質バーナーのレイノルズ数に対する燃焼特性を測定し、火炎限界を求めている。この結果、当量比 0.4 の希薄燃焼を実現した。実験データは数値解析結果と比較され、バーナー内の伝熱特性を明らかにしている。また、これらの結果に基づき、オープンセル状多孔質バーナーの開発指針を示している。

以上要約すると、本研究はオープンセル状多孔質バーナー内のふく射伝熱に関して構築した理論モデルによりバーナー内伝熱特性を解明している。さらに、その有効性を実験的に示し、バーナーの開発指針にも言及している。これは伝熱工学のみならず今日のエネルギー・環境問題にも大きく寄与するものである。また、公聴会において出席者から出された質問に対しても明確な説明がなされた。

よって、本論文を博士（工学）の学位論文に値するものと認める。