ARTIFICIAL NEURAL NETWORK AND NUMERICAL ANALYSIS OF THE HEAT REGENERATIVE CYCLE IN POROUS MEDIUM ENGINE

Udayraj, A. Ramaraju
Department of Mechanical Engineering, National Institute of Technology, Calicut 673601, India

ABSTRACT

Homogeneous Charge Compression Ignition (HCCI) Engines offers lot of advantages over the conventional Internal Combustion Engines. The disadvantages of HCCI such as high HC and CO emissions can be reduced significantly by applying the concept of porous medium combustion. Porous Medium (PM) Engines are the revolutionary concept that is proposed to overcome the disadvantages of HCCI Engines. In this paper numerical analysis of Thermodynamic model of heat regenerative cycle of PM Engine is performed and the effect of various parameters like expansion ratio, initial temperature and maximum temperature are analyzed in efficiency. Artificial Neural Network (ANN) is used topredict the performance of PM Engine and the results are compared with the corresponding values of outputs obtained by Numerical analysis.

KEYWORDS: *HCCI Engine, Porous Medium Engine,Heat regenerative cycle, Artificial Neural Network.*

I. INTRODUCTION

Research in the field of internal combustion (IC) engines has been motivated by the desire to preserve a clean environment and to reduce energy consumption. Reducing exhaust emissions of internal combustion engines are of global importance. Presently,homogenous charge compression ignition (HCCI) engines are being actively investigated worldwide as they can achieve efficiencies close to that of diesel engines while producing low levels of oxides of nitrogen (NOx) and particulate matter emissions. But the disadvantages associated withHCCI Engines are higher hydrocarbon (HC) and carbon-monoxide(CO) emissions[1], the control of ignition timing and combustionrate over the complete operating range. Porous medium (PM) engine, basedon the regenerative or super-adiabatic combustion in porous medium, can reduce the HC and CO emissions to a larger extent[2].Recently, the PM engine has received more and more attention fromnumerousresearchers because of its potential for producing homogeneous mixtures and reducing NOx and soot emissions [3,4].

Premixed combustion within porous mediahas been studied widely and applied to steady combustionwith great successes over the past decades [5,6,7].Consequently,the technique has been then extended from gaseous to liquid fuelsand from steady to unsteady combustion.On this basis, the new concept ofcontrollable combustion in porous media for internal combustionengine was suggested and developed. Durst and Weclas[8] proposed two designs of the PM engine, in one of which a porous mediumcombustion chamber is mounted in the engine cylinder head,fuel is injected into the porous medium chamber, and consequently, all combustion events, i.e. fuel vaporization, fuel–air mixture formation and homogenization, internal heatrecuperation,aswellascombustionreaction occur inside the porous medium. In orderto prove the feasibility of PM engine, they modified a single-cylinder,air cooled diesel engine to incorporate a porous medium reactorin the cylinder head and operated it as a PM engine.

Hanamura[9] designed a reciprocating heat engine, which is similar to a Stir ling engine with super-adiabatic combustion in porousmedia. One-dimensional numerical simulations shows that thethermal efficiency of the engine reached to 57.5% under even verylow compression ratios between 2 and 3, which are much lowerthan those of conventional Otto and Diesel cycles. Weclas[10] proposed a strategy for development of intelligent combustion systems for IC engines, whose essenceis a new concept for mixture formation andhomogeneouscombustionbased on the Porous Medium technology. Macek[11] analyzed the possibilities of homogeneous combustionachieved by porous medium with limited temperature, and foundthermodynamic limits of a new cycle with PM combustion usinghigh flame stability and fast burning at comparatively low temperaturesand the potential of internal heat regeneration. Here we have analyzed the PM heat regenerativecycle in a PM engine and evaluate its thermodynamic performance numerically as well as using ANN. This work is basically the extension of the work done by Hongsheng Liu[3].The engine is derived from one of the designs of Durst[8] and the analysis is based on general idealized cycle model.An ideal thermodynamic model for the cycle of PM engine is presentedto evaluate effects of various working parameters on theperformance of the PM engine.The PM engine is here defined as an internal combustion enginewith a highly porous medium chamber mounted on the cylinderhead (Fig. 1). The PM chamber is thermally isolated from the headwalls and equipped with a valve permitting a periodic contact betweenthe PM-chamber and the cylinder volume.Fig.1shows the complete working cycle of the PM engine advancedby Durst [8].

II. POROUS MEDIUM ENGINE CYCLE

To conduct an ideal cycle analysis of the PM engine, three essential assumptions were adopted in this study:
(1) The heat capacity of porous medium is much larger than that of gas, thus the temperature of porous medium can be regarded as constant and not affected by the heat exchange between the porous medium and the working gas.
(2) Heat losses via the piston, cylinder wall and PM-chamber are neglected. The compression and expansion processes realized were considered as adiabatic.
(3) Instantaneous thermal coupling between the PM-chamber volume and the cylinder. This means that no time elapses during heat transfer between porous medium and the working gas.
Under these assumptions, an idealized thermodynamic cycle with PM heat regeneration in the PM engine can be described with Fig. 2.

The heat added per unit mass of working fluid for the PM heat regenerative cycle is

$$Q_{in} = Q_{2-3} + Q_{3-3'} = C_v(T_3 - T_2) + RT_3 \ln\left(\frac{v_3'}{v_3}\right)$$

Net Work output per cycle is

$$\begin{aligned} W &= W_{2-3} + W_{3-3'} + W_{4-1} \\ &= C_v(T_3 - T_2) + RT_3 \ln(V_{3'}/V_3) + C_v(T_1 - T_4) \end{aligned}$$

The cycle efficiency for the PM heat regenerative cycle 1–2–3–3’–4–1 is

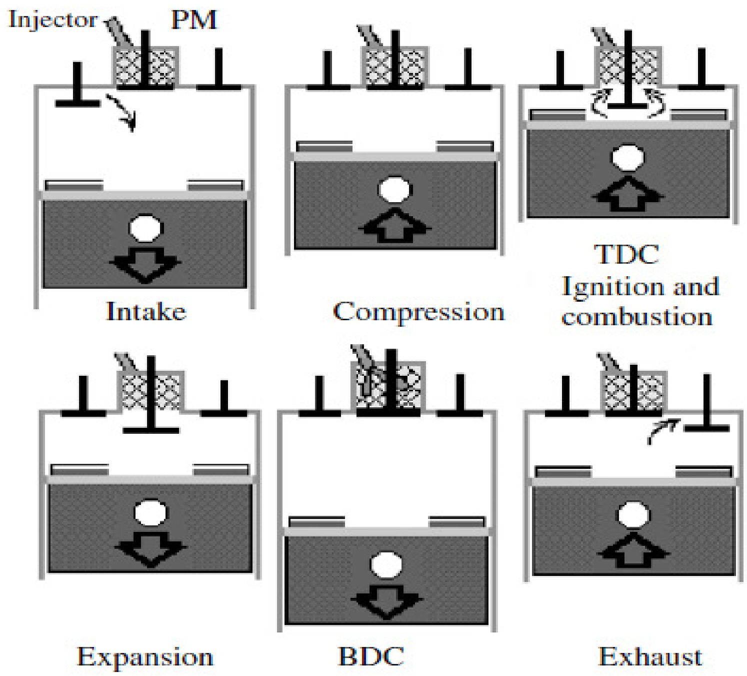


Fig.1.Principle of the PM engine proposed by Durst [8].

$$\eta = 1 - \frac{T_3(\rho/\varepsilon)^{k-1} - T_1}{T_3 - T_1\varepsilon^{k-1} + (k-1)T_3 \ln \rho}$$

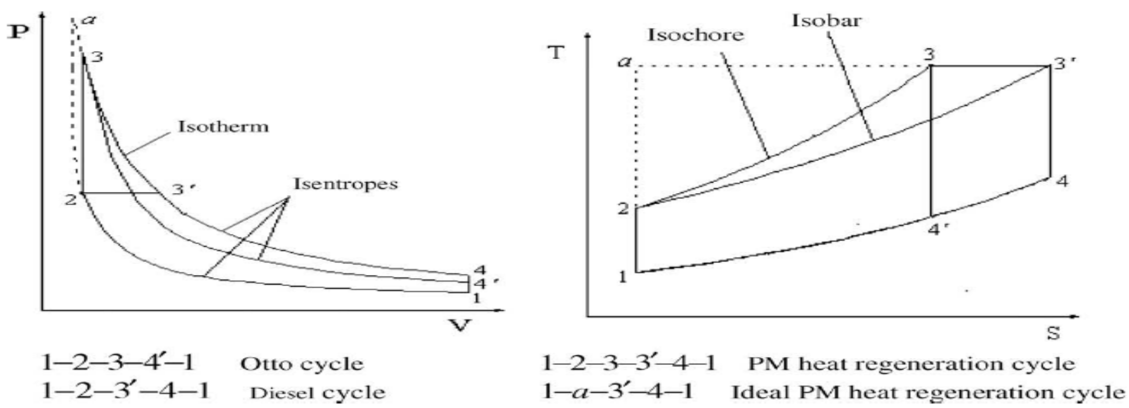


Fig.2.Comparison of Otto, Diesel and PM heat regeneration cycle[3].

III. NUMERICAL RESULTS

A parametric study was conducted to analyze effects of ρ, T1 and T3on the characteristics of the net-work output versus efficiency forPM heat regenerative cycle with ideal thermodynamic model.Range of the various parameters is shown in Table 1. Results of the calculationsfor above parameters ranges are shown in the Fig.3 and Fig.4.

Table1. Range of various parameters

Parameters	Range
Initial Temperature,T1	300K to 350K
Expansion Ratio, ρ	1 to 2.5
Maximum Temperature, T3	1600K to 2000K
Ratio of Specific Heats, k	1.4
Constant volume Specific Heat, Cv	0.7165 KJ/Kg.K

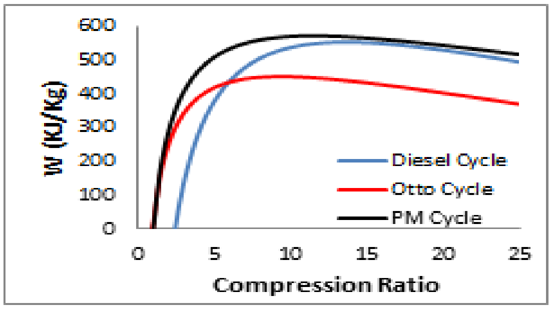


Fig.3. Comparison of the Net Work output for Otto, Diesel and PM heat regeneration cycle.

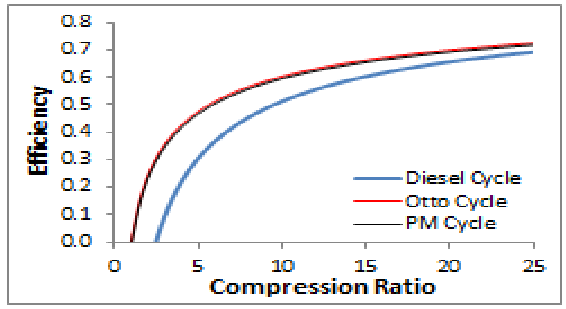


Fig.4. Comparison of efficiency for Otto, Diesel and PM heat regeneration cycle.

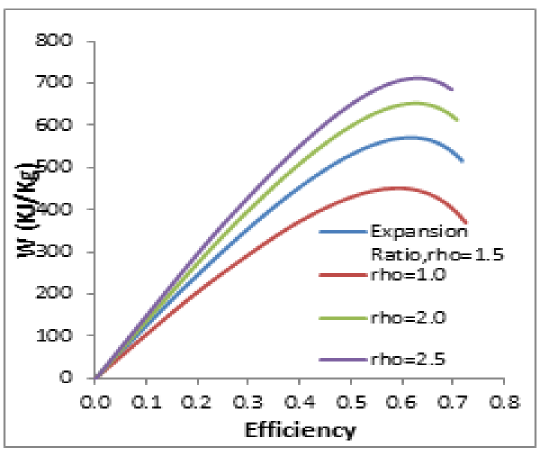


Fig.5. Influence of ρ on the Net Work output versus Efficiency characteristic

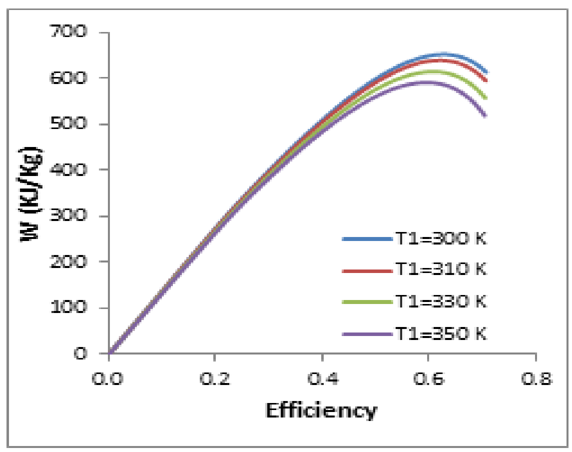


Fig.6. Influence of T1 on the Net Work output versus Efficiency characteristic

For an actual engine, the compression ratio must exceeds certainvalue to ensure the realization of the actual cycle, therefore, the net-work output of the PM heat regenerative cycle must be largerthan that of actual Otto and Diesel cycle. That means the PM heat regeneration cycle can provide significantly more net-work outputat little expense of thermal efficiency.

Fig. 5shows the influences of the expansion ratio (ρ) on the net-work output versus the efficiency for the PM heat regenerative cycleat a condition of T1 = 300 K and T3 = 1800 K. It is shown that there exists a maximum net-work output for constant expansionratio, with the increase of the expansion ratio, the maximum net-work output increases greatly and the thermal efficiency corresponding to the maximum net-work output increases also. Whenthe expansion ratio equals 1 the cycle becomes an Otto cycle, whose net-work curve is much lower than others.

Fig. 6 shows the effects of the initial temperature T1 on the network output versus the thermal efficiency for the PM heat regenerative cycle at a condition of ρ = 2.0 and T3 = 1800 K. The maximum net-work output decrease with the increase of the initial temperature, however, the change is not very evident.

Fig. 7 shows the effects of the maximum temperature T3 on the net-work output versus the thermal efficiency for the PM heat regenerative cycle at a condition of ρ = 2.0 and T1 = 300 K. It shows that there exists a maximum net-work output for constant maximum temperature.With the increase of the maximum temperature, the maximum net-work output increases evidently and the thermal efficiency corresponding to the maximum net-work output also increases.

These results are in good agreement with the results obtained by Hongsheng Liu, MaozhaoXie, Dan Wu [3] as shown in Fig.8 and Fig.9.

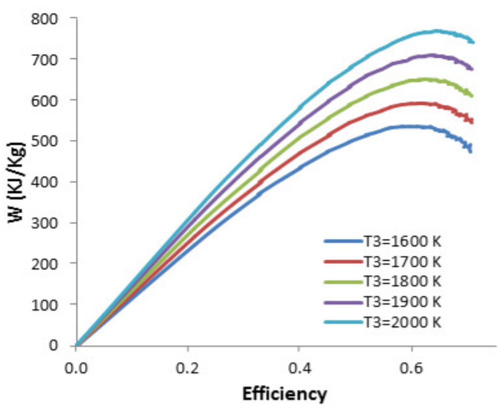


Fig.7. Influence of T3 on the Net Work output versus Efficiency characteristic

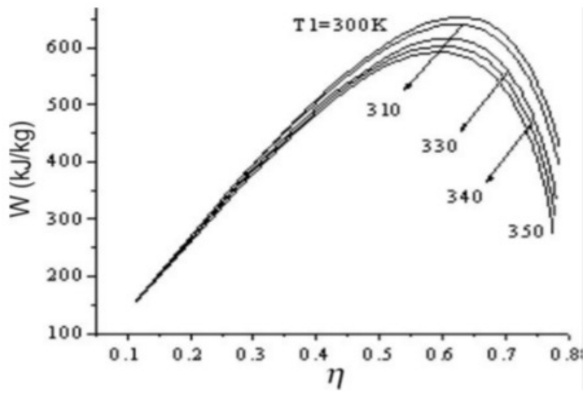


Fig.8. Influence of T1 on the Net Work output versus efficiency Characteristic (Hongsheng Liu, MaozhaoXie, Dan Wu)

IV. ANN ANALYSIS

An artificial neural network (ANN) is an information processing paradigm that is inspired by the way biological nervous system.In a simplified mathematical model of the neuron, the effects of synapses are represented by connection weights that modulate the effect of the associated input signals, and nonlinear characteristics exhibited by neurons is represented by a transfer function. The neuron impulse is then computed as the weighted sum of the input signals, transformed by the transfer function. The learning capability of an artificial neuron is achieved by adjusting the weights in accordance to the chosen learning algorithm.

A typical artificial neuron and the modeling of a single layered neural network is shown below. The signal flow from inputs x_1 , ... x_n is considered to be unidirectional, which are indicated by arrows, as is aneuron's output signal flow (O). The neuron output signal O isgiven by the following relationship:

$$O = f(net) = f \sum_{j=1}^{n} w\, x_j$$

Where, $x_j$the weight vector and the function f (net) is referred to as an activation (transfer) function. The variable net is defined as a scalar product of the weight and input vectors,

$$net = w^T x = w_1 x_1 + \cdots + w_n x_n$$

Where, T is the transpose of a matrix and in the simplest case, the output value O is computed as

$$O = f\ (net) = \{1\ if\ w^T \geq \theta\ and\ 0\ otherwise\}$$

Where, θ is called the threshold level and this type of node is called a linear threshold unit.

The ANN approach has been applied to predict the performance of various thermal systems. The useofANNsfor modeling theoperationofinternalcombustion engines is a more recent progress. This approach was used to predict the performance and exhaust emissions of diesel engines [12]and the specific fuel consumption and fuel air equivalence ratio of a diesel engine [13]. The effects of valve-timing in a spark ignition engine on the engine performance and fuel economy was also investigated using ANNs [14].

The output of the network is compared with desired output at each presentation and errors were computed. These errors were then back propagated to the ANN for adjusting the weight such that the errors decrease with each iteration and ANN model approximated the desired output. The network is trained till the chosen error goal of 10^{-6} is achieved. The schematic of a feed forward network is shown in Fig.10.

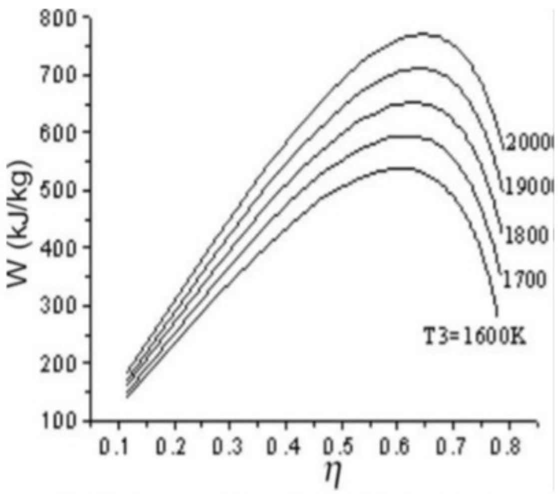


Fig.9. Influence of T3 on the Net Work output versus efficiency characteristic.(Hongsheng Liu, MaozhaoXie, Dan Wu)

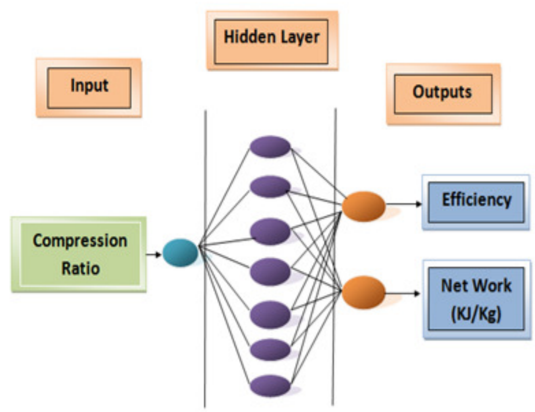
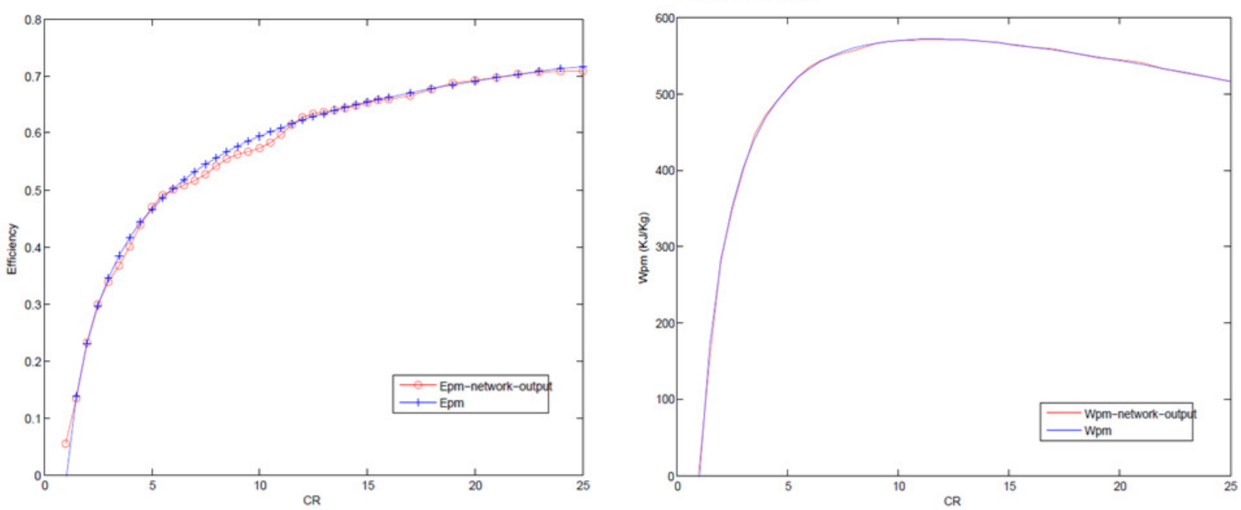


Fig.10. Representation of feed forward network for single hidden layer



(a) (b)

Fig.11. Comparison of ANN predicted results with numerical results

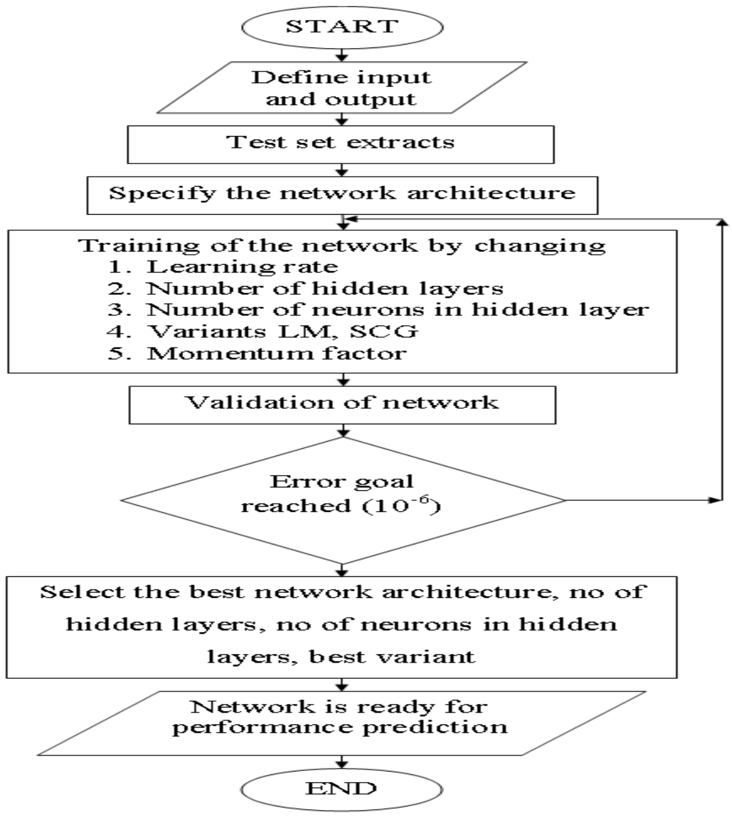


Fig.12. Flow chart of the ANN used for performance prediction.

In the present study, back propagation algorithm with variant LM is used. Finally the ANN predicted results are compared with numerical results for measuring the performance of thenet-work(Fig.11.).The flow chart for the development and training of the ANN networkmodel for performance prediction of a dual-fuel engine is given inFig. 12. ANN used forperformance prediction was made in MATLAB(version 7.0) environment using neural network tool box. Basedon the performance results of the network, the best network architecture was selected. It is chosen for performance prediction of a porous medium engine.

V. CONCLUSION

This study demonstrates an ideal model of the PM heat regenerative cycle in a new type of PM engine. The novel feature of the PM heat regenerative cycle is the heat feedback and an isothermal heat addition process are realized by using the porous medium as a heat recuperator. Numerical computations shows that the PM heat regenerative cycle can provide much larger net-work output than that of an Otto cycle at a little expense of thermal efficiency, and the effects of expansion ratio and limited temperature on the net-work output are evident. The results obtained could provide significant guidance for the performance evaluation and improvement of practical PM engines. A simulation model is developed using ANN to predict PM engine performance which is very reliable.

REFERENCES

[1] Heywood, J. B., 1987, *Internal Combustion Engine Fundamentals*, McGraw-Hill, New York.
[2] Ashok A. Dhale, Gajanan K. Awari, and Mahendra P. Singh,Analysis of internal combustion engine with a new concept of porous medium combustion for the future clean engine,
[3] Hongsheng Liu, MaozhaoXie, Dan Wu,Thermodynamic analysis of the heat regenerative cyclein porous medium engine.EnergyConversion and Management 50 (2009) 297–303.

[4] XIE MZ, New type of internal combustion engine superadiabaticenginebased on the porous-medium combustion technique.JThermSciTechnol2003;3(2):189–94.
[5] Chan WP, Massoud K. Evaporation-combustion affected by in-cylinderreciprocating porous regenerator. ASME 2002;124(6):184–94.
[6] Kakutkina NA. Some stability aspects of gas combustion in porous mediacombustion. Explosion Shock Waves 2005;41(4):395–404.
[7] Mishra SC, Steven M. Heat transfer analysis of a two-dimensional rectangularporous radiant burner. IntCommun Heat Mass Transf 2006;33(2):467–74
[8] Durst F, Weclas M., A new concept of I.C. engine with homogeneouscombustion in a porous medium. COMODIA 2001:467–72.
[9] Hanamura K., A feasibility study of reciprocating-flow super-adiabatic combustion engine. JSME Int J 2003;46(4):579–85.
[10] Weclas M. Strategy for intelligent internal combustion engine withhomogeneous combustion in cylinder. ISSN 1616-0762 SonderdruckSchriftenreihe der Georg-Simon-Ohm-FachhochschuleNürnberg Nr; 2004.
[11] Macek J, Polášek M. Via homogeneous combustion to low NOx emission. In:Proceedings of EAEC congress – CD-ROM. Bratislava: SAITS; 2001. 1:1–10.
[12] CenkSayin , H. MetinErtunc, Murat Hosoz , Ibrahim Kilicaslan , Mustafa Canakci, Performance and exhaust emissions of a gasoline engine using artificial neural network, Applied Thermal Engineering 27 (2007) 46–54.
[13] V. Celik, E. Arcaklioglu, Performance maps of a diesel engine, Applied Energy 81 (2005) 247–259.
[14] M. Golcu, Y. Sekmen, P. Erduranli, S. Salman, Artificial neural network based modeling of variable valve-timing in a spark ignition engine, Applied Energy 81 (2005) 187–197.

Authors Biographies

Udayraj received B.Tech degree from G.B.P.E.C., Pauri - Garhwal, Uttarakhand, India in 2010 and pursuing M.Tech from N.I.T. Calicut, Kerala, India. His interested fields of research are Internal Combustion Engine and Computational Fluid Dynamics.

A. Ramaraju received B.Tech degree from Kerala University, Kerala, India in 1974, M.Tech degree from Calicut University, Kerala, India in 1978 and PhD. from IISC, Bangalore, India in 1990.He has been working inteaching and research profession since 1978. He is now working as Professor in Department of Mechanical Engineering at N.I.T. Calicut, Kerala, India. His interested fields of research are Internal Combustion Engine, Computational Fluid Dynamics, Refrigeration and Air-Conditioning.