Abstract

This thesis presents an analytical treatment of some gradually evolving coherent problems of thermodynamic optimization with engineering importance to propose some physical theories. The first problem is related to the characteristics of macroscopic organization in a class of fluid flow systems. With the findings of the first problem, the second addresses the heat transfer issues of insulation design for nonconjugate heat transfer systems. The third problem is extended to a class of conductive-convective type conjugate heat transfer systems, as a successor of the second. Based on the concepts build in the first problem, the fourth discusses the thermodynamic issues of heat flow with reference to a thermoelectric generator which is a natural heat engine as well as a category of insulating system. The fifth and final problem inculcates the issues of real heat engine as a consequence of fourth. The abstract of each problem follows in order.

In analyses of engineering systems, fundamental quest remains the *distribution* of certain entities (matter, energy) into the space. Thus certain definite forms are generated to serve a specific purpose. *Bejan's constructal theory specifically deals with such optimal* geometrical constructions. In the first problem, equipartition theory is revisited from macroscopic standpoint with reference to some fluid flow systems. It is noted that equipartition principle is a corollary of a more generalized formulation—the constructal theory. It is seen that equipartition principle leads to certain power laws with which certain entities are distributed. This constitutes a deterministic law of nature in some finite length and time scale. Thus equipartition principle is to be recognized as an authentic basis of design for most efficient systems, which in turn obeys constructal principle of organization in nature.

The second problem documents the method of synthetic constraint, a physical principle, to be applicable in the fundamental methodology of conductive heat flow, in replacement of calculus of variations and other optimal control theories. In particular, the optimum distribution of limited volume of insulating material on one side of a plane wall as well as cylindrically curved surface is obtained when the amount of insulating material is uninfluential to the imposed exponential temperature profile. The same physical theory is exercised for a generalized case of a stream suspended in an environment of different temperature and where the exponential wall temperature distribution is affected by the amount of insulation added. The result obtained conforms to those existing in open literature. Further from the physics of the problem it has been argued *that a minimum exists for such* class of problems of heat transfer from an insulated wall. Finally, it has been synthesized that Schmidt's *criterion for the fin design, the tangent* law of conductive heat transport and

Fermat's principle in geometrical optics are but special stipulations of the method of synthetic constraint, which in turn is a corollary of constructal law. Thus the basis for analogies among physical theories is sought. The fundamental solution exhibits a category of equipartition principle.

The third problem reports an alternative treatment in lieu of the principle of variational calculus for a certain class of optimization problems. In particular, the optimum distribution of insulating material on one side of a flat plate for minimum heat transfer is sought when the other side is exposed to a laminar forced convection. Both conjugate and nonconjugate formulations of the problem are conceived and closed form solutions are presented. Interestingly, optimized insulation profile exhibits a category of equipartition principle in some macroscopic domain. Expression for minimum heat transfer is a function of Biot number in nonconjugate analysis of the model. Contrastingly, another dimensionless group is found to be the characteristic parameter for conjugate formulation. Finally, Bejan's method of intersecting asymptotes is employed to find an order of magnitude for a ceiling value of the wall material. With some scale factor, a range for the representative material volume can be ascertained, beyond which the optimization exercise reduces to a trivial one and traditional constant thickness profile becomes a recognized design.

In the fourth problem finite-time thermodynamics, a subfield of irreversible thermodynamics, is employed to model a cascaded thermoelectric generator, which incorporates all the essential features of a real heat engine. Control volume formulation of a cascaded thermoelectric element was carried out over a small but finite temperature gap to comply with the principles of irreversible thermodynamics. Three important dimensionless parameters are identified to designate poor Thomson effect as well as low thermal conductivity and low electrical resistivity of a good semiconductor or semimetal. For ideal values of these parameters it has been demonstrated that exactly half of the Joulean heat *arrives* at both hot and cold junction when temperature maximum passes through the longitudinal center of the thermoelectric element. In general when Thomson heat cannot be neglected, the maximum and the minimum permissible length of any individual module of a cascaded thermoelectric device is predicted involving thermoelectric properties of the materials and passing current. It is observed that maximum permissible length is devoid of dependence on applied temperature gradient whereas the minimum allowable length is not. When half the Joulean heat *affects* hot end and half the cold side, thermal conductance inventory is allocated equally between the high and low temperature side for best possible device performance. Finally, it has been argued that the choice of constancy of total conductance is not only a natural constraint but also a purely realistic design criterion for heat engines or refrigerators. Such design prescriptions those lead to the prediction of shape and structure in any flowing system is reported in open literature as constructal principle.

The fifth problem reports an analytical investigation of the optimal heat exchanger allocation and the corresponding efficiency for maximum power output of a Carnot-like heat engine. To mimic a real engine, the generalized power law for the resistance in heat transfer external to the engine, relaxation effect in heat transfer, bypass heat leak and finally internal irreversibility of the power producing compartment of the engine is taken into consideration. From the engineering perspective the temperature ratio of the heat source and sink as well as to that of hot end and cold side of the working fluid is considered not to be the controllable parameters. A parametric study is presented for the other possible controllable variables. Selection of a power law over a linear model has a significant effect on the optimal heat exchanger allocation for maximum power output and the corresponding efficiency. For a higher degree of relaxation effect the drop in the maximum power efficiency is prominent along with the shift of equipartitioned allocation of heat exchanger inventory. Bypass heat leak and internal irreversibility exhibits relatively less pronounced effects on the maximum power efficiency and on the optimal heat exchanger allocation. Thus the endoreversible formulation of thermodynamic model is physically realistic. Strikingly when the optimal allocation of the heat exchanger inventory obeys the principle of equipartition in macroscopic organization for the linear law of the external heat resistance, the thermal efficiency appears to assume representative documented value. Hence the linear model is also capable of capturing the essential features of a real power plant.