Much effort has gone into research on improving the emissions from combustion processes. These have addressed the reduction of oxides of nitrogen (NO_x) and sulphur (SO_x), the elimination of unburnt hydrocarbons and carbon monoxide. In some cases, this has led to minor improvement in the ability to recover more heat from the exhaust gases, but these effects are only minimal in the best conditions. The conditions under which these improvements occur are attained through fan forced steady combustion processes. In terms of greenhouse gas production from a combustion process this adds typically 3% to the effective CO_2 emission total. In the current global warming climate this is undesirable.

The main purpose of burning fuel is to drive a desired process to produce a product by getting the released energy into the process as efficiently as possible. Most combustion engineers have concentrated on the combustion process itself. They have ignored what happens to the released energy.

In considering what happens to fuel, F, in a process, some of the energy ends up in the reactants and products, Q, and the rest as losses, L. The losses are determined in part by:

1) unburnt fuel;
2) the process temperature;
3) the size of the plant; and
4) the process temperature.

Unburnt fuel can be minimised by improving the combustion process itself. The unburnt fuel normally consists of some hydrocarbons and carbon monoxide. In considering the above list, the second item is fixed and only the last two can be changed to lower the losses from the process. For both these items, the plant size and the exhaust
temperature have to be lowered. The flip side of decreasing the plant size is that other methods driving the process of getting the liberated combustion energy into the process have to increase. The quantity of liberated combustion energy used in the process is determined by:

the heat transfer coefficient U;

the heat transfer area, A (which in turn controls the plant size); and

the difference between the combustion/flue gas temperature and the process, ΔT.

In summary:

$$F = Q+L \qquad (1)$$

i.e.,

$$F = U.A.\Delta T. + L \qquad (2)$$

If A is increased, L will also increase. Thus to maximise Q and minimise L, only U and ΔT can be increased, whilst the physical size of the plant has to be reduced. Increasing the flame temperature can increase ΔT, but for most combustion processes this only increases the NO_x. This is undesirable. If the heat transfer area is decreased, not only has U to be increased to compensate, but U also has to be increased to transfer more heat into the process.

There have been efforts to improve the heat transfer from fluids by flow pulsation (West & Taylor (15); Linke & Hufschmidt (9); Darling (3); Lemilich & Armour (8); Jackson & Purdy (6); Baird {1}; Milburn (11); Milburn &.Baird (12); Keil & Baird (7)). A mechanism to enhance the heat transfer has been obtained through solenoid switching of the flow direction or pulsing the flow via a piston or set of pistons. The increase in the heat transfer coefficients obtain in these tests was of the order of 70%. Similar work has been done on enhancing mass transfer coefficients. Chandhok *et aI.* (2) showed that under the correct conditions, the mass transfer coefficient could be increased by 2 orders of magnitude. The main influencing factor is not the frequency of the pulsations, but the amplitude. The higher the amplitude the larger the increase in the transfer coefficient. There are many pulsating combustion patents granted, but mainly for Helmholz and Schmidt type of combustors.

Pulsating combustion is the consequence of a combustion instability that is driven into resonance by the geometry of the burner. Normally. combustion engineers avoid combustion-generated instabilities at all costs, since they can very quickly lead to catastrophes.

Rijke-type tube combustion has been known since 1777, when Dr Higgins (Higgins(5)) demonstrated his "singing flame" and this is the earliest form of a Rijke tube. It takes its name from the work done by Rijke (14) in the 1850's in an open ended vertical tube containing a heated gauze in its lower half. In the 1890's the technology manifested itself as the pyrophone, similar to a pipe organ, but driven by combustion sources instead of an air supply. The theory underlying the generation of sound waves in Rijke Tubes was proposed by Lord Rayleigh (13) and when heat release meets the Rayleigh Criteria, a resonant set of frequencies are generated in a Rijke tube. There are several different forms of pulsating combustor designs. All of these designs, except the Rijke tube, requite some form of va1ving system to admit the air and fuel into the combustion chamber in a periodic manner.

Traditionally there are 3 types of pulse combustors. These are the Schmidt Tube (closed/open ends, quarter wave system), the Helmholtz Resonator (closed/open or open/open system) and the RijkeTube (open/open half wave system).

The Schmidt Tube was developed in Germany and is usually divided into three sections, namely (1) the inlet, (2) the combustion chamber and (3) the tail or exhaust pipe. The inlet section consists of one-way valves which open or close depending on whether the combustor pressure is lower or higher than the pressure up stream of the valve.

The Helmholtz Resonator consists of a rigid wall cavity which has at least one short and narrow neck through which the enclosed fluid can communicate with the external medium. Due to the neck effect, the size of the device is less than a quarter of a wavelength.

The third type of pulse combustor is the Rijke Tube where a heat source in the lower half of a vertical tube results in acoustic mode excitation. The Rijke Tube is an example of an open cylinder resonator. When a heat source is positioned inside the tube or cylinder and towards one end, it will produce a strong tone at the resonant frequency of the tube. Air passing up the tube is heated and expanded producing a pulse of air toward the centre of the pipe. This pulse of air starts the system into oscillation at its natural frequency.

Among the first accounts of thermo-accoustic activity is that of Rijke himself in 1859. The Rijke tube is a half wave pulse combustor since the acoustic wavelength is actually twice the length of the tube. It appears that maximum amplification occurs when the heater or heat source is located at or around the middle of the bottom half of the tube. At that location, both acoustic pressure and velocity are non-zero. The cylindrical air column with both ends open will vibrate with a fundamental mode such that the air column length is one half the. wavelength of the soundwave. Each end of the column must be an antinode for the air motion since the ends are open to the atmosphere and cannot produce significant pressure changes. For the fundamental mode, there is one node at the centre, the basic wave relationship leads to the frequency of the fundamental, f_i, for a tube of length L in which the velocity of sound is V_{sound}:

$$f_i = V_{sound}/4L$$

It was always thought that a Rijke Tube had to be vertical and straight in order to work. This restriction has to date always curtailed its application to any useful process. A process has been developed that enables Rijke Tubes to be used in a wide variety of useful compact geometries. Amongst these is a superheated steam boiler. In this system there are no valves and the fuel (either in a vapour or a gaseous form) is burnt continuously.

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