EXPERIENCE WITH SOLID WASTE AS A SUPPLEMENTARY FUEL

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ABSTRACT

The introduction covers the historical development of the Imperial Metal Industries Ltd. Power Plant and the psychology behind that development.

The investigation into the concept of firing solid waste into boilers is detailed, as well as the final design parameters.

Details are given of the performance achieved so far, including the problems that had to be overcome.

Finally, the author gives his opinion of advantages to the energy industry and the community.

INTRODUCTION

At no other time was energy under scrutiny to the extent that it is now. To industries that are heavily dependent on energy, not only is there concern about energy costs, but there is grave concern about availability.

In a situation of crisis proportions, the ingenuity of engineers is being tested in such diverse fields as solar power, wind power, wave power and the contents of this paper, power from refuse.

As with any new development, there are difficulties to overcome, but if the reward is of value, then solutions can be found.

HISTORICAL BACKGROUND

The Imperial Metal Industries Ltd. site in Birmingham began in 1862 when two small sheds were erected on an isolated plot of land to manufacture ammunition. The site was well away from the population in the city. It was from this small 4-acre plot that the present 230-acre complex developed. The prime mover in its early development was George Kynoch.

George Kynoch preferred, when possible, to make “all the ingredients of the Company’s productions”. Following this doctrine, the site processed its own glycerine. This left by-products particularly suitable for making soap and candles, so what could be more logical than to make soap and candles.

The erection of soap and candle factories was by no means the only novelty introduced by George Kynoch. A steel melting plant “prepared the Company to supply merchants and manufacturers in Birmingham with all descriptions of castings in mild steel”. A rolling mill and new casting shop was erected so that most of the brass required for the ammunition works was provided from within.

One hundred fifteen years later, from these small beginnings, the Imperial Metal Industries, Kynoch Works, now employs over 7000 people. It produces copper and brass strip, sheet, rod, wire and foil. It is one of the largest producers of titanium and other new metals outside of the United States. Metal components and assemblies are supplied through a vast range of industries from pen cases to foreign coins. The main plant manufacturing “Lightning” zip fasteners resides on the site. “Kynoch Press,” a high quality pub-
lishing house, owes its origins to George Kynoch's desire to produce his own wrappers, boxes and posters. Ammunition manufacture continues to play a significant part of the site's activities, though its activity is aimed mainly at the sporting users rather than military needs.

In this atmosphere of "do-it-yourself" it would have been out of character if power supplies had been supplied from external sources. In the late nineteenth century most manufacturers had to produce their own power needs, as there was often no alternative, but one feels that George Kynoch would not have considered any power than his own as an alternative.

**IMI POWER PLANT**

A variety of prime movers were installed in the power plant up to 1915. They ranged from gas engines to reciprocating steam engines (whilst there is no record of the manufacturer of the gas engines, it is probable that they were site produced, for it is known that gas engines were manufactured on the site). Most power sources for machine drives were, of course, steam driven and that steam was locally generated. Electricity was mainly for lighting and the station capacity was of the order of 1000 kW.

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Two hundred twenty-five psig (15.5 bars) remained the steam pressure for the power plant up until 1957. During the period 1915-1957, hand fired vertical boilers were replaced by three Babcock & Wilcox CTM. These boilers were fitted with twin chain grate stokers and each had an evaporation capacity of 100,000 lb/hr (45,000 kg/h). In this same period a further six turbo-alternators were installed. They ranged in type from radial flow condensing turbines and radial flow back pressure turbines to axial flow passout turbines. Their capacity varied from 2.75 to 12 MW.

In 1957 approximately 25 percent of electrical demand was produced from back pressure and passout steam turbines. The remaining 75 percent was generated on condensing turbines with only a very limited import. It is impossible to comment on the economic merits of electrical generation from condensing sets with steam conditions at 225 psig (15.5 bars) in the period 1915-57. Commercial records of this period are not adequate enough to make a judgment. Certainly there was a management attitude which was firmly committed to self-generation and I suspect that any justification for new capital outlay on boilers or turbines would have been found almost irrespective of the economics.

The period of 1957-75 saw radical technical changes taking place in the Power Plant. In order to improve the overall station efficiency, a cyclone coal-fired slag tap boiler of 200,000 lb/hr (90,000 kg/h) was installed in 1957, together with a 6.5 MW turbo-alternator. The steam conditions of this topping system were a boiler pressure of 950 psig (65 bars) and a temperature 925 F (495 C) with the turbo-alternator exhausting at 225 psig (15.5 bars).

There is little doubt that this unit proved to be too big for the system that it topped and that the technical problems associated with cyclone fired slag tap boilers were not manageable on such a small system.

The boiler's poor reliability due to tube failures caused by slag and erosion attack placed a heavy strain on plant operations. To give some idea of the scale of the problem, the longest continuous run that the boiler recorded was 4 weeks. Frequently 2 weeks was all that could be achieved.

Small electrical systems, such as the Imperial Metal Industries, Kynoch Works, cannot afford an unreliable plant. The back-up from the grid can be very expensive, due to maximum demand charges incurred for short periods, and it is almost impossible to justify a sufficient standby plant to cope with the tantrums of an unreliable unit, particularly if the unit represents a major percentage of the total generation.

Due to the advantageous price of heavy fuel oil in the mid to late 1960's, an oil-fired bidrum boiler of 140,000 lb/hr (63000 kg/h) was installed in 1967, together with a 5MW turbo-alternator. The steam conditions of this system were the same as the previous topping system.

This particular addition was made up from a proven plant, as far as possible, in order to avoid the weaknesses of the cyclone boiler. The project was largely successful, though the turbo-alternator, which was geared, gave some anxious moments.
The turbine was the sixth machine to be built and fortunately for Imperial Metal Industries, previous machines highlighted gear box weaknesses during the commissioning period and modifications were carried out before failure occurred. This once again illustrates the hazards when installing new generating plant of a type with less than 5 years operational experience.

By 1970, heavy fuel oil was becoming less competitive and the U.K. energy market was benefiting from the North Sea gas fields. Imperial Metal Industries were able to negotiate an attractive 5-year natural gas contract to supply its boiler plant. The contract was for scheduled interruption of supplies during the months January, February and March of each year.

In order to fire the natural gas now available, the two topping high pressure boilers were converted to burn oil and gas. The cyclone boiler, which had been the scourge of the plant when firing coal, now came into its own. A very simple, cheap, quick conversion allowed the unit to operate on any combination of oil/gas mixture from 0-100 percent. The cyclone furnace, which on coal had suffered continual tube failures, was now transformed into one of the finest mixed burners that can be found (tube failures became a thing of the past and reliability became the strongest feature of the boiler).

The bidrum boiler, previously oil fired, was almost as equally successful in conversion. The ability to mix fire proved difficult due to oil flame impinging on the gas burners and completely destroying them. A number of different burner settings were carried out, but without success. Finally we decided to fire either gas or oil but not mixed. This was a less flexible arrangement, as burners had to be physically removed and fitted, but plant operations could accommodate such an arrangement.

Figure 1 illustrates the installed plant in 1972.

The Power Plant’s yearly energy intake was now 60 percent natural gas, 35 percent heavy fuel oil and 5 percent coal. The contrast between firing 100 percent coal and the new multi-fuel system could not have been greater.

**FUEL TRENDS**

In 1972, with the advantage of multi-fuel supplies, studies were carried out on future trends of the energy market. It was not at all comforting. A simple comparison of oil reserves and new finds against consumption illustrated the precarious supply position facing world users in the mid 1980's. In the event, market forces were accelerated by the Arab-Israeli war of 1973 and the energy price explosion took place in 1974, some 10 years earlier than expected.

In earlier deliberations during 1972-73, we had come to the conclusion that domestic refuse was the only other fuel available to the Imperial Metal Industries, Kynoch Works, which was already supplied by the three conventional fuels of oil, gas and coal.

**SOLID WASTE AS A FUEL – DESIGN CRITERIA**

**CONCEPT**

During 1973 some very simple tests were carried out in burning waste material (mainly paper from the works), and our conclusions were that both our chain grate boilers and the cyclone were capable of burning waste, though the former would probably be best suited for such a process. The sudden increase in oil prices during 1974 altered the time-table for the translation of the studies into firm plant proposals from years to months, but at least the principal critical design factors had been decided.

1. The project was aimed at producing a cheap fuel and was not meant to be a method of waste disposal. The waste disposal industry in 1974 was not experienced in the different attitude required from a supplier of a commodity to that required for the disposer of waste. This difference of approach had at all stages to be re-emphasised to the waste industry and is still not often appreciated.

2. Refuse, like any other fuel, has to be prepared for burning, and the optimum preparation would be that which gives stable combustion at the lowest preparation cost.

3. Material likely to have an adverse effect on the combustion process has to be removed within the overall economic remit to produce a cheap fuel. Material which also has a value higher than its heat value should also be removed again within the overall economic limit.

4. Environmental standards had to be maintained to at least the standard achieved with coal firing. In certain locations a change of fuel triggers off a new set of emission standards, and obviously it is then necessary to evaluate the new situation, but this was not the position in Birmingham.
DESIGN CRITERIA EVALUATION

The results on design of the four concepts were then evaluated.

As Imperial Metal Industries interest in refuse was only from the fuel angle, the deliveries of raw refuse to the shredding facility would have to be as and when needed and not necessarily as the refuse arises. This attitude is a reflection of that adopted with conventional fuel.

From studies of the problems in raw refuse storage at many incinerators it was clear that economically the mass storage of raw refuse was not possible at Imperial Metal Industries for the following reasons:

1. The capital cost of large storage bunkers could not be justified. As refuse is only a supplementary fuel, with the boilers able to revert to conventional firing instantaneously, refuse is not an essential element in the generation of steam and it was, therefore, possible to evaluate the cost of bunkers against the reduced fuel cost that the stored tonnage gave.

2. A large floor drop area for raw refuse was considered but was again rejected on economic grounds though not as strongly as the bunker case.

3. The design finalized on a very small reception area which really only permitted the unloading of the largest vehicle, approximately 15 tons.

4. The final factor that settled our ultimate design was the problem that Imperial Metal Industries would have had as boiler operators in disposing of a large amount of raw refuse if, for some reason, the boiler route was not available. Unlike conventional fuels the storage life of raw refuse is approximately 24 hr, and the attractions of its fuel value rapidly decrease the longer the material is held in storage. It becomes increasingly unpleasant and difficult to handle with time. Large scale storage, therefore, had distinct operational difficulties with no economic incentive.

Basic requirements for the complete combustion of any fuel is that the air and fuel are brought into contact under the right conditions and in the right proportions.

The right conditions for this chemical reaction demand adequate combustion time, turbulence and correct furnace temperatures.

Each fuel, whilst requiring consideration of all these combustion conditions, does so with greatly differing degrees of magnitude.

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FIG. 1 IMI KYNOCH WORKS POWER PLANT 1972
A crude analysis of domestic refuse quickly puts it in the "difficult" fuel category with a wide range of demand conditions within itself. The high moisteries, ash, together with the wide range of materials both in size and composition, are the principal reasons affecting this assessment.

1. High moisture slows the combustion process, particularly the ignition stage. This problem may be tackled either in the furnace or with addition of drying treatment external to the furnace. The decision as to which route to take is dictated by the economics with regard to capital and operational costs, both being affected by the type of boiler already installed in a retrofit situation.

In the Imperial Metal Industries situation, fitting of a drying process was not easy because of physical limitations in the Boiler House. As important to the engineering considerations, however, was our lack of information with sufficient detail and accuracy, to make a judgment as to drying design features or whether to dry at all.

We knew that the moisture content of refuse without drying would be higher than our normal fuel to cater for high moisture contents would not be higher than those encountered in peat and brown coal. We knew that many incinerators operate without predrying external to the furnace and maintained ignition without the use of auxiliary fuels.

From these very broad facts we finally decided not to predry and to rely on the combustion stability given by our normal fuel to cater for any variations resulting from high moisture refuse.

2. Refuse is screened in a number of incinerator operations to remove the fine material which is usually inert. Imperial Metal Industries, therefore, to assess the need for screening as part of the pretreatment before firing. We estimated that the ash from refuse could be up to twice the tonnage that would be expected from coal on an equivalent heat basis. As the ash arrangements on all our boilers were generously designed, we saw no problem in that area.

We decided that it was not possible to judge the effect of higher ash so far as combustion was concerned, and felt that we would have to have firing experience before we could come to a decision on prescreening. A screening plant was therefore not fitted.

3. In order to bring the air and fuel into contact as quickly and as uniformly as possible, fuels have to be broken down in particle size if their original state is too big in order to present as large a surface as possible to the flame. In addition, all fuels have to be introduced into their combustion air in a controlled but turbulent manner.

With refuse there is not only a considerable variation of particle size, but also a considerable variation in the heating qualities of constituent materials.

In view of these two problems, it is desirable to breakdown and "homogenize" the material and these two processes can be achieved in a shredding operation. Imperial Metal Industries, therefore, decided that a shredding operation was essential, but the particular boiler route to be taken (i.e., stoker or cyclone) would decide the degree of size reduction required.

In considering materials undesirable in the combustion process or possessing higher market value in their own right than as a fuel, having already dealt with ash and moisture, we identified ferrous and nonferrous metal, glass and plastic.

1. Extraction of ferrous metal from refuse, particularly shredded refuse, is a common operation. There are established outlets for the metal sales, and the economics of the operation are easily evaluated. Ferrous metal contents of between 8-10 percent are sufficiently high to provide an attractive income from the capital employed.

Imperial Metal Industries, therefore, decided to install ferrous extraction equipment, and in order to maximize the process placed it after shredding.

2. The highest nonferrous metal content that could be found in the United Kingdom refuse was less than 2 percent. Of that 2 percent the bulk of the metal was aluminium contaminated with other materials.

The development of nonferrous extraction equipment was fairly new and far from tested equipment. We therefore decided to ignore nonferrous extraction in our installation.

3. Glass contents vary from 8-10 percent in raw refuse. The market for glass is extremely selective and we were unable to find a stable long-term outlet. Even if a market could be found, the equipment to extract the glass, other than by hand, did not exist on a commercial scale in 1973.

We were concerned that the fine glass may fuse on the fire bed and cause "biscuit clinker"; on the other hand, there was an equal chance that the dispersal of the fine particles could be so widespread that conglomerates may be avoided.

It was finally decided to fire the pulverized
glass into the boiler furnace and dispose of it with the other ash residues. As Imperial Metal Industries sell this ash for civil engineering work, we would at least be receiving approximately $2 per ton for the glass so fired.

4. Approximately 1.5 percent of refuse is plastic. Plastic, of course, is highly desirable for its heat value, but the PVC elements are less desirable due to their chlorine content.

Chlorine and its effects on boilers is one of the most discussed subjects in the combustion field. The considerable problems that have accompanied 100 percent refuse fired incinerators, particularly those with heat recovery equipment, rightly indicate caution to the potential fuel user.

In the United Kingdom, coals with chlorine contents of 0.25 percent are common, and the Imperial Metal Industries, Power Plant, has burned such coals for over 50 years without suffering abnormal corrosion.

Our calculations indicated that the chlorine content of refuse was in fact equal to that of our coal on a thermal basis, ie, 0.25 percent. Whilst we did not understand the mechanics of the absence of severe corrosion in our boilers, when incinerators firing similar chlorine content fuel suffered so badly, we felt that the continued presence of coal in conjunction with refuse would result in a neutral condition.

As there was a poor market for salvaged plastics and no reliable equipment available to extract, we decided to exploit the heat value and tolerate the chlorine.

Our gravest concern for the emissions from our stacks was in the area of solids. If we chose the chain grate boilers route, we would be introducing semisuspension firing with a fuel high in moisture and ash. Each of these features could increase the solids content of our gases.

The cyclone boiler was fitted with an electrostatic precipitator and we were confident that it had adequate capacity to cope with refuse emissions. However, our chain grate boilers had multicyclone grit arrestors and we doubted the ability of these units to meet any increased loading.

An examination of the weakness in our multicyclone arrestors quickly revealed the final separator as the main factor. We concluded that by passing the dirty gas stream through a more reliable filter the multicyclone grit arrestors would be able to cope with a higher dust burden.

FINAL DESIGN

Having evaluated the design criteria, Imperial Metal Industries had next to decide on which of the two boiler routes to be taken. As previously stated, we had the choice of chain grate boilers or a cyclone slag tap boiler (PC).

Our original preference was to adapt the chain grate boilers as they gave fuel a furnace retention time of up to 30 min and this is particularly appropriate for refuse. We had to accept, however, that if the cyclone boiler route could be adopted, then we would benefit from the thermal gains of that particular cycle, but we had to cater to a furnace retention time of seconds. To burn off fuel in seconds requires the fuel to be presented in the furnace in micron size.

1. CHAIN GRATE BOILER ROUTE

We were confident that the chain grate boilers could accept all domestic refuse providing it was predominately less than 6 in. (150 mm) and did not contain more than 30 percent moisture. There is ample evidence in the incinerator field to support this conclusion. Equally, there is ample evidence in the refuse shredding field to accurately assess the cost of size reduction down to 6 in. (150 mm).

We were able, therefore, to cost fairly accurately the pretreatment necessary for chain grate boilers.

2. CYCLONE BOILER (PC)

Micron-size reduction with coal is normally achieved in one single pulverizing mill. Coal, however, arrives in reasonably uniformed size and is easily broken down. Refuse has neither of these qualities.

Examination of the systems under development to prepare refuse for pulverized coal boilers involved multistage shredding, air classification, screening and many other novel devices.

We believe that multistage shredding would be required to achieve micron size reduction.

We did not discover any air classifier that worked to our satisfaction. When handling such a variable material as refuse, the demand that is being placed on an air classifier is considerable. The density of materials such as paper changes
with moisture content, whilst plastic does not. Finely ground glass adheres to other materials so diverting the desired route of itself or possibly the carrying medium.

In 1974 we at Imperial Metal Industries did not believe that there was a reliable air classifier available on the market to meet our needs; we have still to be convinced.

After the rejection of air classifying and an assessment of the cost of both capital and operation of multistage shredding, we came to the conclusion that the economic reduction of refuse to micron size was not feasible. Without micron size reduction, the pulverized coal route was not possible.

Our choice of boiler was now clear; the chain grate boilers were clearly the more practical solution and provided the greatest possibility for success.

**PLANT INSTALLED**

**LOCATION**

The following factors dictated that the refuse firing facility had to be split into two separate plants.

The power plant is situated in the most congested area of the works and the addition of further "external" vehicles was undesirable.

As the Imperial Metal Industries works is handling high value metals, for security reasons we keep vehicle movements onto the works to a minimum.

There was some apprehension at the possible nuisance of odor if raw refuse was to be delivered in an area crowded with plants and offices.

With the consideration of the above factors, the facility was split into two parts, a reception, shredding ferrous metal extraction, and container loading plant.

At the power plant we had to provide a container unloading capability in addition to the firing equipment.

**SHREDDING PLANT**

The shredding plant was constructed at the north end of the works where it was possible to provide it with its own access from a public road and it was isolated from other plants. The plant is represented by the top line 1-3 on Fig. 2. The plant is fairly typical of many 15 tons/hr shredding operations.

Refuse is received from a West Midlands Council transfer station in 10-ton containers (compacted). The containers tip into the reception pit which is fitted with an apron conveyor (Fig. 1). The conveyor, by virtue of its angle of inclination and the position of training strips, provides steady feed into the mouth of the mill.

The shredding mill is a 42F Tollemache vertical shaft machine with a rated throughput on domestic refuse of 15 tons/hr.

A considerable amount of investigation was carried out before choosing a vertical shaft machine as against a horizontal machine and our final decision was due to the following reasons:

1. The machine does not have grates at the discharge but achieves its shearing action throughout the materials passage through the full length of the hammer pattern.
2. The machine requires a simple foundation and is easily adaptable to a variety of in-feed and outlet conveyor layouts.
3. The power requirements were lower than horizontal shaft machines.
4. The replacement of hammers is easy and can be carried out by plant operators without the assistance of skilled help.

A conveyor elevates the shredded material to a height of 20 ft (6.15 m). At the discharge point, ferrous scrap is removed by an in-line overband magnetic separator. We chose an in-line position at the point of discharge because that is the most obvious point at which a magnet can operate most effectively, deflecting metal from a falling stream.

Shredded material less the ferrous metal extracted is then carried by a reversible transfer belt either to the left or right hand of the main discharge belt into containers.

The containers are top loaded and demountable and fill two functions. They transport the shredded refuse to the power plant, a distance of 1 mile, and by having containers surplus to that required for transportation they provide a buffer storage capacity. We felt that a buffer was necessary and preferred to have it in multiple small lots (approximately 6 tons) rather than a single mass.

The containers are top loaded along their full length by an open helical screw. The refuse enters the front top of the container from the transfer belt, builds up until it reaches the helical screw hinged some 6 in. (150 mm) above the container,
and the screw then carries refuse along until the container is full.

A probe detects when the container is full and automatically switches the loading system to the opposite hand.

POWER PLANT

The power plant refuse installation is represented by the bottom line 4-6 on Fig. 2. The containers are delivered from the shredding plant as required and are off-loaded onto a tipping device which discharges them into a hopper that is fitted with a full-width apron conveyor 10 ft (3.07 m) wide.

The conveyor is inclined and has a variable speed control, and this control governs the rate at which shredded refuse is fired into the boilers.

Originally steel beams were fitted across the hopper with a knife edge facing the moving refuse. These beams were at staggered heights above the conveyor along the length of the hopper with the intention of progressively reducing the height of the discharged refuse from approximately 6 ft (1.84 m) to 6 in. (150 mm).

Following initial trials, levelling screws had to be fitted at the top of the hopper and in line with the conveyor before satisfactory metering was achieved.

Metered refuse is carried by conventional conveyors to the rear of each of the two modified chain grate boilers and discharged into air streams that carry the material into the furnace.

The injected material is fired horizontally, from the rear wall of the boiler to the front wall at a height of about 4.5 ft (1.38 m) contra to the grates movement.

The boilers are Babcock and Wilcox CTM each fitted with twin style 28 grates.

OPERATING EXPERIENCE

Commissioning began in November 1975, and many of the handling problems associated with refuse were experienced immediately.

The shredding operation, being relatively conventional, gave few problems after the initial start-up problems that affect any new plant. The Power Plant equipment, however, was new and unproven and the first refuse discharged into it quickly revealed its deficiencies.
REFUSE FEED CONTROL

As already described, the hopper at the power plant was originally fitted with static knives so that from an initial height of up to 6 ft (1.84 m) the shredded refuse would be reduced to a regular height of 6 in. (150 mm) at the conveyor discharge. The knives were totally inadequate for the job. Refuse, instead of being cut back, simply compressed at each stage until the conveyor was firmly jammed due to the pressure being exerted. Repeated attempts produced repeated failures.

After several weeks of trials with various devices such as chains and loosely hung knives, the decision was taken to fit levelling screws across the top of the discharge end of the conveyor, the screws lying parallel with the conveyor. We had observed the successful operation of the container-loading screws at the shredding plant, and were quite certain that the same action would take place in the metal feeder hopper.

Five helical screws were fitted, the intention being to run the two outer screws with the conveyor movement and the center screws in the opposite direction. After months of trials with various combinations of rotation, it was found that the best effect was to have all screws operating against the conveyor movement. In this mode we found that the resultant tumbling action broke up the refuse, "fluffing" up any compacted fractions and generally airing the material to the benefit of combustion.

Considerable trouble was experienced with the variable speed drive and the overload protection shear pins. This was a result of under-design due to incorrectly estimating the pressures placed on the conveyor in cutting refuse down to a regular height. The fitting of screws eased this problem, but even so we had to introduce greater gearing reductions and size shear pins up to the maximum possible.

The first boiler converted had two burners fitted to the rear wall. This arrangement necessitated splitting a single refuse stream into two. Again we tried a single static knife and quickly suffered the inadequacy of a static device, as had occurred in the meter feeder hopper. We finally fitted two small belts each feeding its own burner. This arrangement requires an even spread on the initial feed conveyor and this to date has only been partially successful when on loads less than half-full load.

The carrying medium into which the refuse falls for injection into the furnace is air. In order to make full use of existing equipment, we originally used the overfire air fans. Unfortunately, the air velocities that we could achieve with these fans was satisfactory for only the lower loads, and frequent blockages occurred when loads above 50 percent were attempted. Individual fans were finally fitted to each burner, designed to give twice the air pressure that was obtained from our overfire fans. The change proved successful.

COMBUSTION CONDITIONS

During the period that we were solving the problems related to the refuse feed conveyors and fans, there was little that could be accomplished with combustion, as this was conditional on a steady feed of fuel. When we began to benefit from the feed improvements, it became possible to investigate conditions in the furnace.

The nominal particle size we were shredding at was minus 2 in. (50 mm). At this particle size we found frequent blanketing of the fire, particularly under wet conditions. After several experiments it was found that minus 3 in. (75 mm) gave the best overall performance; even so, if a particular load of refuse had a high degree of fines in its raw state, blanketing could still occur.

As no fines are taken out at any stage of our operations, all glass is pulverized and fired into the furnace. We felt that with the glass being so finely divided and dispersed, the particles would adhere to the coal ash and remain dispersed, rather than form into biscuit clinker or slag. No clinker or slag problems have been suffered at any time, so we believe our original theory was correct.

Moisture in refuse varies considerably. Analysis of material received into our plant has varied from 20 to 50 percent. The higher values undoubtedly took us by surprise. We have found that the high levels occur at times of rainfall and are directly proportional to it. As most of the West Midlands refuse is placed into sealed cans and plastic bags, we cannot understand how rainfall can find its way into the refuse in the quantities that it does. Combustion can tolerate up to 30 percent moisture, but above this figure deterioration begins. Above 40 percent moisture, refuse is no longer a practical fuel without pre-drying. However, in Birmingham rainfall rarely reaches the levels which produce refuse with moistures in excess of 40 percent and we decided that the most economic solution was to stop refuse operations at times of very heavy rainfall.
estimating such periods at less than 10 percent per year.

Refuse as a fuel is also affected by the behavior of moisture even in the 25 percent moisture range. We have observed that refuse freshly shredded will combust more readily than if held for 24 hr. The distribution of the same quantity of moisture changes with storage to the detriment of ignition. This phenomena is still being studied.

Solid emissions are currently being checked and preliminary results indicate a slight drop in emissions when firing domestic refuse as against 100 percent coal, and a slight rise in emissions when firing predominately paper waste as against 100 percent coal. These studies were delayed until our combustion conditions were satisfactory, and this took longer than had been anticipated.

Manchester University is carrying out corrosion tests, but these are long-term and no results are yet available. Deposits taken from the boilers have not shown any increase in acidity over those found when coal firing, so we do not expect any acceleration to take place due to supplementary refuse firing.

**ECONOMIC PERFORMANCE**

It has taken nearly 2 years to settle the plant down. There have been numerous modifications and in more recent times delivery difficulties in the supply of raw refuse. We can, however, now make an accurate prediction of the cost versus savings situation.

Cost at shredding rate of 10 ton/hr:

- Power 10 kW/ton @ $0.02/kWh = $0.2/ton
- Maintenance = $0.5/ton
- Labor @ $3.50/man hour = $1.5/ton
- Total = $2.2/ton

Savings:

- Scrap sales @ $20/ton = $1.20/ton
- Ash sales @ $2/ton = $0.5/ton
- Heat value (4500 Btu/lb) = $18.14/ton
- Coal $1.8 per million Btu = $18.03/ton
- Less lower boiler efficiency due to moisture loss = $1.81/ton
- Total Savings: $18.03/ton
- Value per ton raw refuse: $15.83

These costs and savings relate to U.K. conditions and in the cost side I would expect the U.S. situation to be higher and, as yet, your fuel savings to be lower.

It is worth noting that in the Imperial Metal Industries economic evaluation there is no contribution from the waste disposal facility being provided and this could be significant in the U.S.A.

In any situation it is necessary to take note of all the elements that make up a waste firing operation. An important aspect of the IMI approach is to make as much use of existing equipment and circumstances as possible. Almost each conversion will be different either in plant layouts or economics or both.

We believe, however, that where there are water tube stoker boilers situated within a few miles of a refuse dump, then an evaluation study is worthwhile. In some cases the refuse will be either too wet or the tonnage replacement possible will be too low for an economic conversion to be worthwhile, but in the majority of cases very good returns on investment will be available.

**CONCLUSIONS**

The problems of the increasing cost of waste disposal and energy are mounting every day and both topics have, and are continuing, to attract a great deal of attention from many directions. A great deal of money has and is being spent in ways to reduce further costs in both areas.

The amount of money that has now been spent on various projects designed to evaluate the extraction of energy from waste amounts to millions of dollars. This expenditure must by now have revealed to the industry what will work and what will not work.

From our own experience at Imperial Metal Industries we are now satisfied that domestic refuse can be an economic supplementary fuel to normal coal firing, but it is necessary to bear in mind the following points:

1. Domestic refuse can only be a low grade fuel which even the most sophisticated treatment cannot increase substantially.
2. Very careful evaluation is required to assess the cost of each step in the treatment process. Keep the system as simple as possible.
3. The moisture content of domestic refuse is extremely variable and is rarely going to fall below
15 percent.

4. Give very careful study to the size of the operation. The advantages of scaling up can quickly turn sour when the subject matter is refuse.

5. Boiler operators must remember that they cannot solve all the problems of waste disposal. He can, however, reduce his boiler costs if he treats refuse as he would any fuel.

6. Waste disposers must remember that they are not going to solve the energy crisis. Boilers can, however, become another disposal point and one which may be able to reduce some of their costs.

7. Again, both boiler operators and waste disposers must remember that refuse is a low grade fuel. It can be a difficult fuel.

8. This paper describes one method in extracting the energy in domestic refuse. There are other methods and there will be still more solutions in the future. Each plant, area and solution will be tailored to its own particular set of circumstances. Even though there are difficulties that must not be underestimated, this is a subject in which all participants can benefit and not least of all the community can dispose of waste more economically and in a way which is environmentally more satisfactory.

Key Words
Boiler
Combustion
Economics
Energy
Fuel
Separator
Shredding
Discussion by

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This is an outstanding contribution to the art of using shredded refuse as a coal supplement in industrial boilers. The fact that refuse is not an ideal fuel is stated explicity and repeatedly and then is voluminously depicted as the many problems are described. In fact, this is a paper on materials handling of municipal refuse delivered in 10-ton transfer trucks to an industrial plant which has undertaken and mastered the difficult task of shredding, cleaning, conveying, and firing the processed refuse as fuel in two traveling-grate fired boilers.

A striking and significant aspect of this paper is that it is mostly about materials handling and says very little about combustion of the shredded refuse, merely this: (1) that above 40 percent moisture it is not a practical fuel, (2) that too many shredded fines “blanket” the traveling grate stoker fuel bed, and (3) the glass does not form a troublesome sheet clinker on the non-agitating traveling grate. Apparently there were no problems with complete combustion and the grate residue is marketable as fill.

There are many useful pointers in this paper for anyone contemplating the burning of shredded refuse. The most important of these is conclusion number one: “Domestic refuse can only be a low grade fuel which even the most sophisticated treatment cannot increase substantially.”

Two major uncertainties detract from this paper: (1) emissions control has not been resolved. The eventual addition of a very high efficiency fly ash collector as would be required in most communities will increase the costs significantly, and (2) the capital costs are not shown. Actually, many waste-to-energy plant owners find that the owning costs are at least half the total annual costs. A significant aspect of the plant’s economic environment is the author’s observation that over the years, “. . . the management’s attitude was firmly committed to self-generation (of electricity) . . . almost irrespective of economics.” Apparently a similar attitude prevailed regarding the use of domestic refuse as a supplemental fuel. From an overall energy-efficiency point of view this is commendable. We need to find ways to encourage this policy in more of those industries where cogeneration is thermodynamically sensible.

Discussion by

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The author is to be commended for this paper and the contribution it makes to improving ecology through resource recovery from processing solid waste.

Actual operating experience with firing processed waste (RDF) is vitally needed to simplify the waste processing procedures. It is also needed to establish reliability of the process and maximize the reuse of resources. With this need, it is unfortunate the author devoted more than half of the paper to historical background in the development of the power plant and state-of-the-art aspects of solid waste processing. The value of the paper would be increased by providing the following additional information:

1. Analyses and heating values of MSW as received, freshly shredded RDF, and RDF after 24 hr storage. This information may help clarify why RDF combusts less readily after 24 hr storage.

2. Characterize the differences between domestic waste and paper waste and include analyses and heating values.

3. Provide boiler operating performance including:
   - Steam flow, pressure and temperature
   - Coal feed and heat input
   - RDF feed and heat input
   - Air flow and temperature
   - Gas flow and temperature
   - Gas temperature throughout unit

4. Provide operating data on particulate emissions obtained when firing 100 percent coal, domestic waste, and paper waste. If the particle sizing was determined, this information would be useful.

5. Clarify the reference to the pulverization of the glass. At SWARU in Hamilton, Ontario when Tollemache (Heil) shredders are used, the glass is only shattered (up to \( \frac{1}{4} \) in. - \( \frac{1}{2} \) in. size) and passes from the grate to the residue without any change in characteristics. The relative cool temperature of the grate maintained the shattered glass particles at a temperature well below their fusion
point and the glass could be clearly identified in the ash. It is hoped that the author may provide this data in his closure and further increase the value of this paper.

Discussion by

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Reading the Abstract, Introduction, Historical Background, IMI Power Plant and Fuel Trends chapters, one wonders about the relationship of these chapters to the title of the paper. Beginning with the "Solid Waste as a Fuel-Design Criteria," however, everything falls in place and follows to logical conclusions.

Although somewhat short on specific technical data, the paper is a valuable contribution to the technical literature, especially in view of its candor in reporting technological and operational problems and the logical approach to solutions, lacking most of the time in contemporary publications on solid waste processing technology.

Mr. Marshall should be congratulated for his contribution to the industry.