Automobile Shredder Residue: Process Developments for Recovery of Recyclable Constituents

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CONF-901211--2

DE91 006038

1 INTRODUCTION

Each year, the secondary metals industry recovers about 40 million tons of ferrous scrap, which is used in the production of finished steel products. The single largest source of this scrap is the obsolete automobile. The automobile shredder industry recovers about 10-12 million tons per year of ferrous scrap. However, for each ton of steel that is recovered, about 250 lb of residue remain. The automobile shredder residue (ASR) is made up of the nonmetallic content of the automobile, which contains plastics, glass, fibers, and foams, as well as dirt, gravel, and sand. It is also contaminated with automotive fluids. The plastics content of ASR is typically about 20% by weight, but this percentage is expected to increase over the next decade because of the significant increase in the use of automotive plastics over the past 10-15 years. At present, ASR is landfilled. The rapidly escalating cost of landfilling and the growing environmental concerns about the contaminants and the fate of this waste in landfills, are motivating scientists and engineers to look for alternatives. Research has been ongoing to identify and develop recycling technologies that will reduce the volume and mass of ASR going to landfills.

Most of the previous research has focused on exploiting the plastics and other hydrocarbons content of ASR for secondary recycling (e.g., production of wood products substitutes) and for quaternary recycling (e.g., cogeneration). Limited work was also conducted on tertiary recycling (e.g., pyrolysis and gasification). Argonne National Laboratory (ANL) is testing a procedure to selectively dissolve and recover individual key thermoplastics from ASR. This approach (which could be considered as primary recycling of these plastics) might be a more cost-effective option, given the relative values of plastics.

The objectives of this paper are threefold: (1) to briefly outline the structure of the automobile shredder industry as a supplier of ferrous scrap, (2) to review the previous research that has been conducted for recycling ASR, and (3) to present the results and implications of the research being conducted at ANL on the development of a process for the selective recovery and recycling of the thermoplastics content of ASR.

DISCLAIMER

2 AUTOMOBILE SHREDDER INDUSTRY PERSPECTIVE

Figure 1 summarizes the processes involved in the recycling of a scrapped automobile. In 1988, the approximately 200 shredders in the United States supplied in excess of about 10 million tons of recovered ferrous scrap to the iron and steel industry. The major investment of a shredder operator is in the shredder machine, which is driven by a 3000-6000 hp motor. No thermal energy is required in the process. Magnetic separators and air classifiers are downstream from the shredder. The shredded objects end up in three fractions: ferrous scrap, nonferrous scrap, and ASR. The cost of disposal of ASR has skyrocketed from about $5/ton in 1985 to over $100/ton in some areas in 1990. Worse, as landfill space is becoming very scarce, no economical and environmentally acceptable disposal alternative is commercially available. Some shredders in the United States and Canada were forced to shut down because they could no longer dispose of ASR properly and economically. This dilemma will be further exacerbated by the increasing percentage (due to increased use of plastics in automobile manufacturing) of ASR compared with the percentage of recovered metals. Unless a technology to handle ASR is developed, ASR will affect the viability of this industry and will eventually affect the supply and price of high-quality scrap.

3 EARLY RESEARCH AND DEVELOPMENT EFFORTS

Earlier research and development work related to ASR concentrated mainly on two areas: incineration (quaternary recycling) with and without heat recovery and secondary recycling of the ASR based on its plastics content. To a lesser extent, tertiary recycling was also investigated.

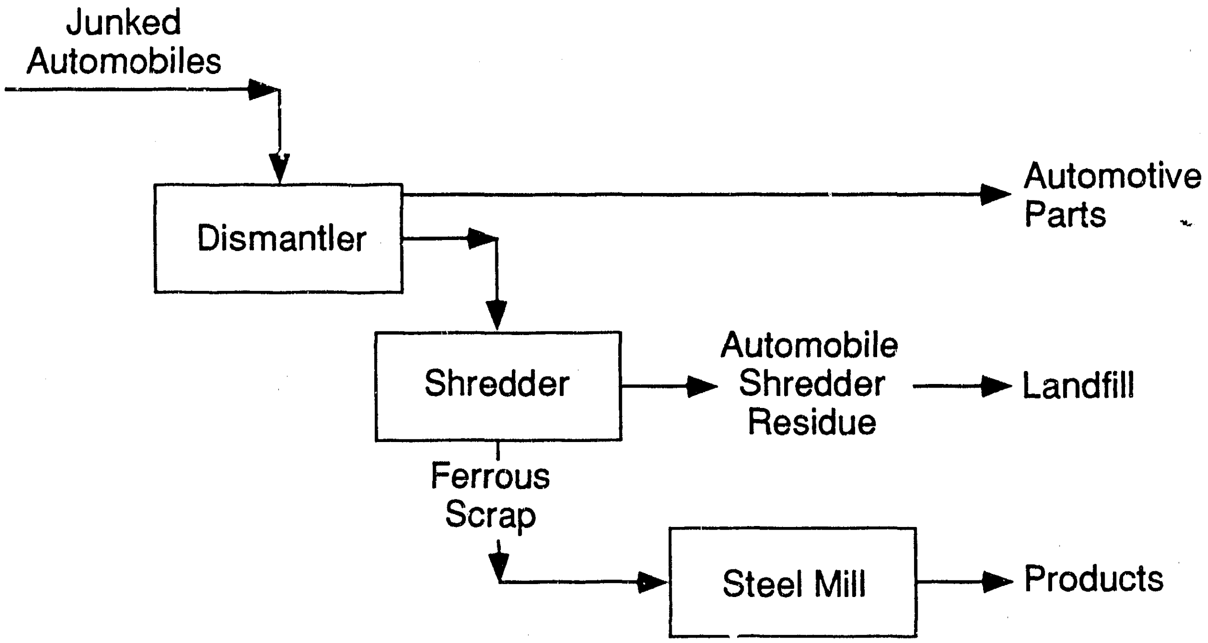

FIGURE 1 Processing of Obsolete Automobiles

3.1 INCINERATION

Prior to the introduction of the automobile shredder in the early 1960s, a common method of recycling obsolete automobiles involved open-air combustion of the automobile hulk to burn off the plastics and other combustibles, leaving behind the metals. This method is no longer practiced because of its gross violation of environmental (Clean Air Act) regulations. More controlled incineration techniques, with and without heat recovery, were explored since the late fifties [1-5]. Although incineration can result in more than a 50% reduction in the weight and over a 75% reduction in the volume of ASR, incineration is relatively costly and has not been accepted as an option for handling ASR. This lack of acceptance is due to a combination of economic, environmental, and logistic problems, some of which include the following:

1. Because ASR contains high concentrations of chlorine (3.5 wt%) and sulfur (0.5 wt%), appropriate scrubbing techniques are required. Although the technology for scrubbing HCl and SO_x exists, adequate scrubbing of these materials is expensive (especially when present in high concentrations, as is the case in ASR).

2. The high chlorine content, in particular, will make the flue gas very corrosive, which will also increase the cost of building the incineration system and the cost of its maintenance.

3. Many shredder facilities shred varying amounts of "white goods." These goods include household appliances, which are equipped with old capacitors that may contain polychlorinated biphenyls (PCBs). Although standard practice is to manually remove capacitors for appropriate disposal prior to shredding, some contamination of the ASR may occur. Governing regulations require that PCBs be incinerated at very high temperatures (about 2000 °F). High-temperature incinerators are very costly to build and maintain. Supplementary fuel might also be required to attain such temperatures, and this fuel will further add to the cost of such facilities.

4. A high chlorine content is suspected of enhancing the chances of producing dioxins and benzofurans during the combustion process, especially if the combustion process occurs at temperatures that appear to favor the production of these species. Therefore, it is anticipated that permitting of such incinerators will be subject to a complicated process, which may call for excessive and costly chemical analysis.

5. Location of incineration facilities in general suffers tremendously from the "NIMBY" (not in my backyard) syndrome. Therefore, it is anticipated that the finding of a suitable location will be time consuming and would involve a major and costly public relations campaign.

6. Thermal energy (which can be recovered from incineration) cannot be used directly in most shredder facilities. It could be used to produce electricity. An

analysis conducted by the authors indicates that an electricity cost of over \$0.09/kWh and a disposal cost of over \$40/ton is required for on-site power generation to break even with landfilling of ASR.

A recent report published by The Center for Materials Production (formerly the Center for Metals Production) [6] addressed incineration using more specialized techniques, such as fluidized bed burning, plasma melting, and submerged arc melting.

3.2 SECONDARY RECYCLING

The most comprehensive research regarding secondary recycling of ASR was that funded by the Energy Conversion and Utilization Technologies (ECUT) branch of the U.S. Department of Energy [7]. This form of recycling was pursued because of the high plastics content of ASR. The thermoplastics can be heated and remelted into different products without having to achieve a high degree of separation of impurities. Products such as park benches, lamp posts, road traffic furniture, shingles, and other construction materials can be made from wastes containing plastics by using state-of-the-art extrusion and molding equipment. The presence of hard and sharp objects in the waste material (such as rocks and glass) could, however, damage the equipment and/or increase its maintenance cost. The market for such products is small, and the cost of making such secondary products is not insignificant. These limitations make it more difficult for these products to compete with their counterparts that are made of virgin materials such as wood, sand, and gravel.

Factors that are to be considered regarding secondary recycling include the following:

- ASR contains heavy metals, which should be locked in the product once the plastics are melted and remolded. However, many plastics tend to degrade slowly in acidic or basic media. Such degradation could result in exposing the metals and make them leachable. The same problem is applicable to oil, PCBs, and other organics that are or might be present in the ASR.

- The quality of products that can be derived from ASR can be upgraded by partial separation of undesired components (such as glass and big pieces of rocks) and by adding virgin plastics and other additives. The appearance of the product can also be enhanced by having the recycled material sandwiched between thin layers made of virgin material.

- The continuously changing composition of ASR demands that tolerances be built into the design of the process in order to regularly meet product specifications and to prevent near-term obsolesence.

The increasing plastics content in cars will make ASR more suitable in the future for making secondary products. However, it is our belief that such products will continue to be difficult to market because of cost relative to conventional products.

Equipment that has been developed or is under development for the secondary recycling of plastics in municipal solid waste streams can be adopted for the secondary recycling of ASR. These equipment include the "Mitsubishi Revezer," "Regal Converter/Kabor K," "Klobie," "FN Machine," "Flita System," and "Remaker." These systems and others are described in References 8 and 9.

3.3 TERTIARY RECYCLING

Some work was also done on the application of tertiary recycling to plastics [8,10,11,12]. Tertiary recycling of the hydrocarbon-based fraction of ASR (plastics, rubber, paper, wood) could produce value-added products such as monomers, solvents, light hydrocarbons, and/or liquid and gaseous fuels. The plastics, however, will be the main source for such products. Processes that may be used for this purpose include pyrolysis, hydrolysis, gasification, and selective dissolution and recovery of plastics.

Pyrolysis, which is the thermal decomposition of organic molecules in an oxygen deficient environment, is a well-known technique [8] for the processing of wood, coal, and municipal waste, although it is not practiced commercially. The product mix is generally a function of the operating conditions, primarily temperature. The major products from polyethylene (PE) are H_2, C_6H_6, CH_4, and C_2H_4; the major products from polyvinylchloride (PVC) are C_6H_6, $CH_2CHC_6H_5$, C_2H_2, and HCl; and the major products from polypropylene (PP) are C_6H_6, $CH_2CHC_6H_5$, and C_2H_2 [11].

We learned from discussions with some shredder operators that some pyrolysis tests were conducted on ASR but no data were reported in the open literature. However, it is safe to assume that the hydrocarbon-based content of ASR can be pyrolyzed, and that at the proper operating conditions, it should give products similar to those reported for the pyrolysis of PE, PVC, and PP.

Hydrolysis was applied to the polyurethane foam (PUF) fraction of ASR [13,14] to produce polyols and amines. Braslaw et al. [13] developed a process to separate and purify the product mix to produce polyols that can replace up to 50% of the virgin polyol used in making high-quality, flexible, low-density foam. The amine products can also be sold for reuse in the chemical industry.

Gasification could also be used to convert the hydrocarbon bases solids in the ASR into a low-Btu gas containing carbon monoxide, hydrogen, and light hydrocarbons. The product gas can be used as a gaseous fuel or it can be used to produce liquid products such as methanol. A high-temperature gasification test was conducted using the gasifier developed by VOEST-ALPINE industieanlagnbau, Ges.m.b.H of Austria [6]. The ASR was blended with other plastics and waste oils. The product was a low-Btu gas. However, minute quantities of several dioxin species were detected.

Selective solubilization of plastics from a waste material is a technique that could be used to recover the plastics in a usable form [12,15] that might qualify for primary recycling. Identification of the right solvents and the right operating temperatures, both for solubilization and separation, are essential to produce sufficiently pure products that can be substituted for or mixed with virgin materials without reducing the quality of the final product.

Argonne National Laboratory is presently testing the selective solubilization technique in the laboratory. The results of this work are discussed in the next section.

4 SELECTIVE DISSOLUTION AND RECOVERY OF PLASTICS FROM AUTOMOBILE SHREDDER RESIDUE: THE ARGONNE NATIONAL LABORATORY PROCESS

Argonne National Laboratory conducted an experimental research program that led to the conception of a three-step process to recover thermoplastics from ASR (Fig. 2). The three steps are physical separation, solvent treatment, and solvent regeneration. These steps are described below.

4.1 PHYSICAL SEPARATION OF ASR

The physical separation step (illustrated in Fig. 3) involved passing the ASR (as received) over a multi-deck vibrating screen separator. A vacuum chamber was connected to the ends of the screens carrying products other than fines. Experiments conducted with various size screens resulted in the selection of three product streams: fines, PUF, and a plastics-rich stream (PRS). The fines, which are less than 1/4 in. in size, made up about 25% of the ASR weight. The fines were further separated using a magnet. Between 30% and 40% of this stream was magnetic material. The magnetic fraction is basically rust (iron oxides). The remainder of the fines consisted of glass, sand, dirt, and some nonmagnetic metals.

4.2 RECLAMATION OF THE POLYURETHANE FOAM

The PUF stream, which was made up about 15% of the ASR weight, was collected with a vacuum system. The PUF was contaminated with automatic fluids and contained some moisture. The PUF was washed first with solvents (such as acetone or hexane) and then was washed with water and detergents. The solvents were recovered, leaving behind about 30% of the PUF weight in oils. The cleaned foam has no odor and no contaminants. However, it contained very small amounts of fabrics and carpet fuzz. A small piece of wire was also found tangled up in the foam. The market value of the recovered foam is still to be determined.

4.3 TREATMENT OF THE PLASTICS-RICH STREAM

The plastics-rich stream (PRS) was first visually inspected for large chunks of metal, which were removed when detected. The stream was then washed with boiling acetone to remove oily materials using a sohxlet-extraction system (Fig. 4). When the acetone was regenerated, it left

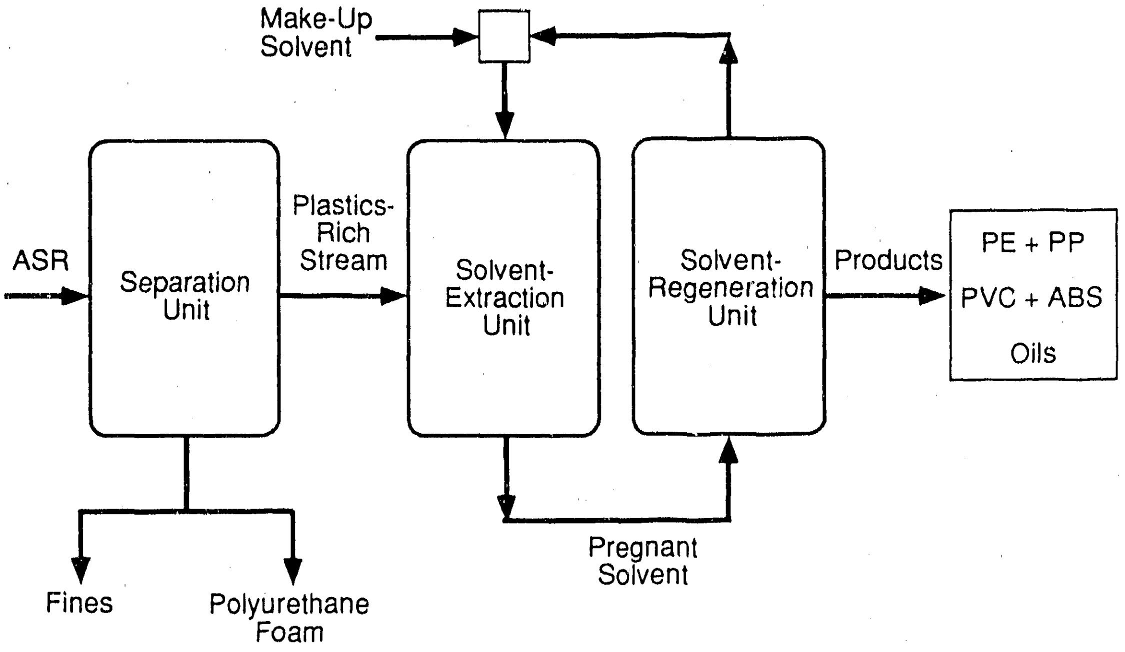

FIGURE 2 Schematic Diagram of the Argonne National Laboratory Selective Solvent Dissolution Method

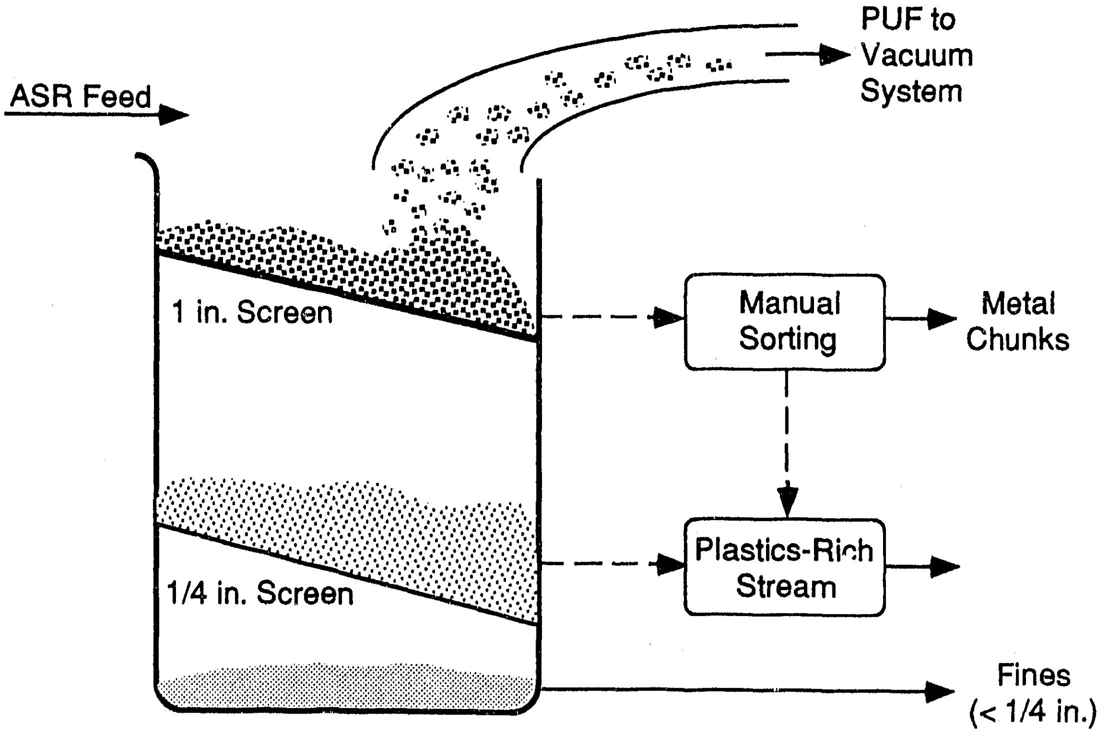

FIGURE 3 ASR Separation System

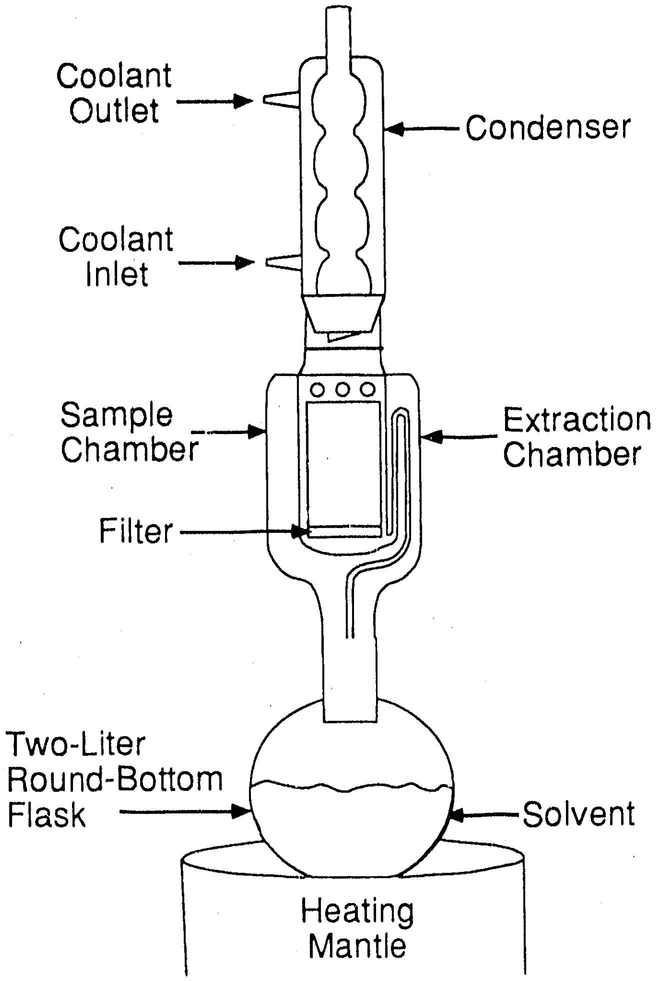

FIGURE 4 Schematic of the Solvent Extraction Apparatus

behind a mixture of oils and some dissolved plastics, such as polystyrene. The cleaned PRS was then treated with tetrahydrofuran or ethylene dichloride in the same apparatus. These solvents dissolved both PVC and ABS. The PRS was then treated with boiling xylene, which dissolved PE and PP again in the same apparatus.

4.4 SOLVENT REGENERATION AND PRODUCTS' RECOVERY

Figure 5 is a schematic representation of the solvent regeneration apparatus, which is a simple distillation unit. As the solvent distills, it leaves behind the plastics that are in solution. Laboratory experience showed that as much as 92% of the solvent could be recovered for reuse. Complete drying of the recovered plastics was not practical in the laboratory because the plastics tend to stick to the glass walls of the apparatus. Higher percentages of recovery are expected to be achievable in commercial applications.

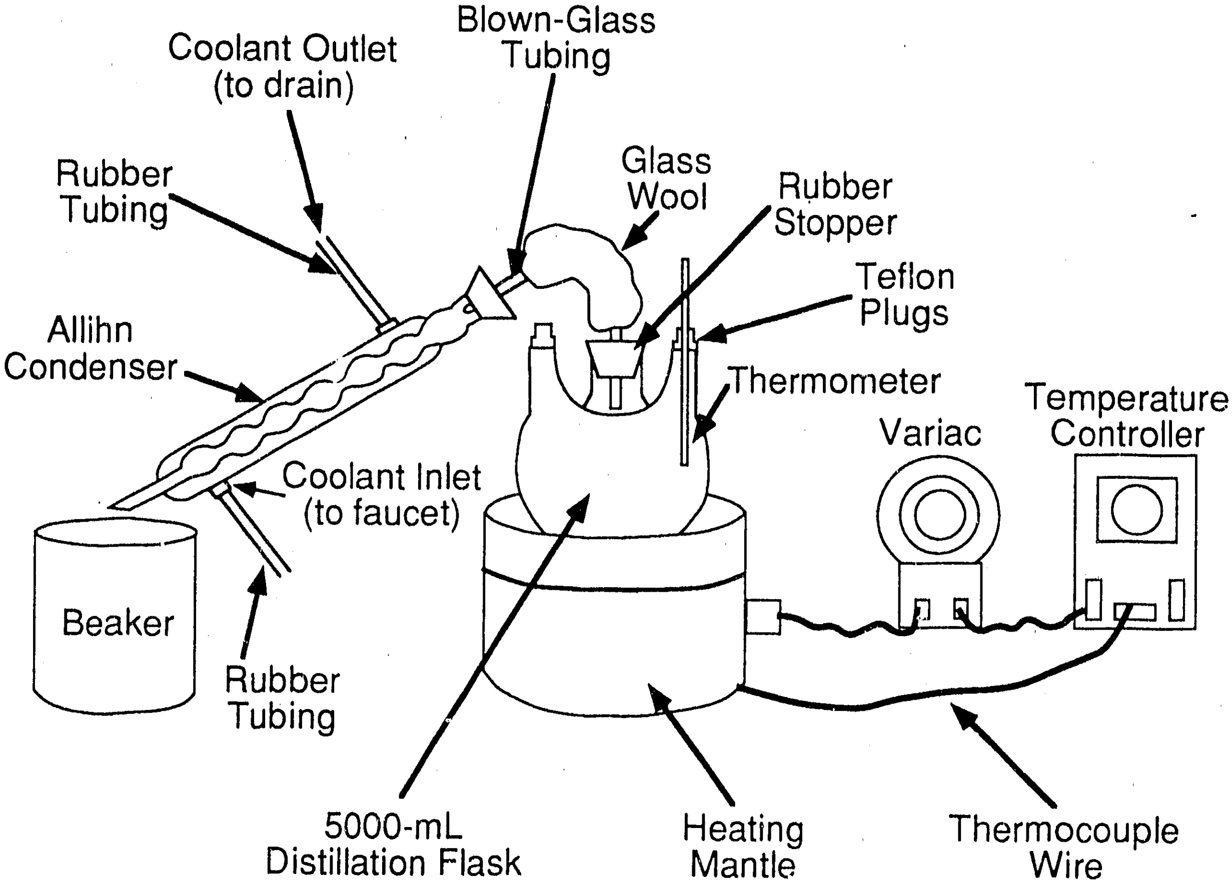

FIGURE 5 Solvent Regeneration System

5 CONCLUSIONS

The viability of the obsolete automobile shredder industry, which is the largest producer of ferrous scrap, is dependent on solving the problem of disposing of its residue. The scarcity of landfill space and its escalating cost present a serious environmental and business challenge to the industry. Incineration of the residue is generally more expensive than landfilling and could result in unacceptable emissions, unless excessive and costly scrubbing equipment are added. Incineration also destroys the value of the recyclable products in the residue (such as plastics). We have developed and tested a process to selectively dissolve and recover the thermoplastics content of the residue. As a by-product of the process, about 10% of the weight of the residue is recovered as iron and iron oxides (rust). This process reduces the mass of the residue by about 50% and reduces its volume by about 70% while recovering potentially marketable products, such as iron oxides, clean polyurethane foam, PVC and ABS, and PP and PE.

ACKNOWLEDGMENTS

Work supported by the U.S. Department of Energy, Assistant Secretary for Conservation and Renewable Energy, under contract W-31-109-Eng 38.

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