2005 Final Report

Fats and Proteins Research Foundation

Low Ash MBM and Poultry Meal – Infrastructure Applications for Terminal Velocity Separated (Elutriated) Product

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II. Industry Summary

Concise Statement of the Major Accomplishments of this Research:

There were three major accomplishments of this research:

1. the development of the Protein Recovery Unit for the fractionation of MBM into its constituents. This is a scalable unit operation with predictable performance and design features.
2. the demonstration of the improvement in concrete properties upon the addition of 2-5% bone portion. This is a major breakthrough since the added material behaves as a concrete admixture which does have significant added value. Admixtures tyopically sell for $ 2 per kg or higher.
3. the production of biodiesel for the neat, in-situ reaction of the meat portion of MBM and the associated recovery of the protein for future use in collagen type applications

Summary

Several processing and application technologies for Meat and Bone Meal have been studied over the past two years at Widener University. The goal is to improve the market potential for the nearly 6 billion kg per year of inedible material from animal production. Specifically, meat and bone meal (MBM) is being subjected to a similar examination given to collagen from corium by the Widener University Collagen Research Group (CRG). Over the past ten years, this group has focused on the development of applications for corium that range from environmental remediation to artificial tissue to infrastructure applications to controlled release. The FPRF project research group is composed of the following members:

three graduate students are assigned to the MBM project –
one is in residence at the USDA and
the other two are conducting experiments at Widener

three senior chemical engineering students
working on the elutriator for their senior project.

The project topics for each student are listed on the Co-Investigator page at the beginning of this report. For all the projects covered by the FPRF sponsored research program, the key areas of study are the pretreatment of the raw MBM (by size fractionation and milling where appropriate) and the assessment of the efficacy of elutriated MBM constituents in infrastructure and other applications.

There is precedent for this approach from the experience with the Collagen Research Group (CRG) at Widener. When the CRG first began the studies on bovine corium, it became clear that the initial processing would be the key to the development of applications. To that end, (also stated in the last progress report), an elutriation unit operation has been successfully developed to separate the MBM, efficiently and in a scalable fashion, into its bone and meat constituents. This unit, named the Protein Recovery Unit (PRU), is now continuous operation on MBM supplied by the USDA (ERRC). Bone fractions with bulk densities of 0.7 g/ml are recovered from the bed while the meat meal with bulk densities less than 0.5 g/ml are recovered in the overhead system of this unit operation.

The separation in the PRU is based on the different terminal velocities of the various constituents in MBM. The apparatus consists of an air fluidized bed plus filter for the collection of light (low terminal velocity) material. Instrumentation includes flow meters, differential pressure gauges, and an exhaust system. This ability to isolate fractions of MBM in a scaleable apparatus should open the door for many applications which only work on a portion of MBM. It is believed that this is the first time such a clean fractionation has ever been reported.

Using elutriated material, and having developed protocols for milling, washing, extraction and drying of the material, the value of the various fractions of MBM in the following major areas are being assessed - infrastructure (composites, admixtures, support, and insulation: >$2 B/y potential) specifically regarding asphalt and concrete. Additionally, the CRG is expanding it efforts into potentially higher valued markets, such as those identified for collagen. These include biodiesel production and environmental remediation based on chelation. The biodiesel production technology employs the fractionated meat meal in a unique process using neat meat meal *in-situ*. This technology has been named Meat Meal In-situ or MMI.

An applications map for the various fractions of MBM has been developed and was included in a proposal for the FPRF (September, 2005). It is also included in the discussion section of this report. This map is based on studies performed by the CRG as well as that reported in the literature. Given the current fear over BSE, the benefits for such applications are clear. Notwithstanding the issue of BSE, the value of MBM in non-feed applications has economic incentive. The map is also attached in the Appendix of this report.

In terms of the work described herein, the four major goals of the research have been accomplished. Some of this research has already been reported at technical society meetings, such as, the American Chemical Society and the American Institute of Chemical Engineers. The work has been universally well received, especially in the graphic representation of the different cuts of the MBM that have been recovered.

The four main goals are listed below:

Goal 1: Fractionate the MBM into a meat rich portion and a bone rich portion

Goal 2: Test the bone portion in infrastructure (large volume, low margin) applications

Goal 3: Process the lipids in the meat portion *in situ* into biodiesel via transesterification with methanol

Goal 4: Recover the protein from the biodiesel for further processing in collagen type applications.

The invention of the elutriator and operating protocols are the key developments in this research. This is the critical technology step in the success of the potential applications. The design and operation instructions for this equipment is available to members of the FPRF upon request.

An additional project being performed by one of the Widener students in residence at the USDA in Wyndmoor, PA (Eastern Regional Research Center) is the use of enzymes (Versazyme) to treat the prions in the original MBM material. This work will per part of the students thesis which will be prepared for presentation by August, 2006.

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IV. Reporting Information

Final report:	Submission Date: January 25, 2006
Submitted to:	Fats and Proteins Research Foundation, Inc. 16551 Old Colonial Road Bloomington, IL 61704
Project Title:	**Low Ash MBM and Poultry Meal – Infrastructure Applications for Terminal Velocity Separated (Elutriated) Product**
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Research Location(s):	Kirkbride Hall, Widener University Bartholomew Hall, Widener University US Department of Agriculture, Wyndmoor, PA

V. Co-Investigators, Project Topics, and Timeline

Co-Investigator(s): **Widener Students and MBM Project Topics**

Sharmila Rao, MS (ChE), August, 2006
(*Elutriation and Collagen Composites*)

Brian Coll, MS (ChE), August, 2006
(*Biodiesel, Prion Destruction*)

Yogi Kurniawan, MS (ChE), August, 2006
(*Biodiesel Production and Protein Recovery*)

Jordan Laster, BS (ChE), May, 2006
Andrew Johnson, BS (ChE), May, 2006
Antoun Mobarek, BS (ChE), May, 2006
(*Elutriation and Infrastructure Applications*)

Megan Winkelman, BS (ChE), BS (Chem), MS (ChE)
(*Protein Characterization and Utilization*)

(*contact information for all students*)

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V. Co-Investigators, Project Topics, and Timeline.........*continued*

Project Timeline:

Project Started: September 1, 2004

Project Completed: January 1, 2006

External Presentations on the FPRF Project Topics:

1. ACS National Meeting (2004) – Philadelphia
   [Sharmila Rao, G. J. Maffia]

2. ACS National Meeting (2005) – San Diego
   [G. J. Maffia, Donna Stauffer]

3. International Conference on Solid Waste Technology and Management - Philadelphia

   [2005 – G. J. Maffia
   2006 – Yogi Kurniawan, G. J. Maffia
   2006 – J. Laster, A. Johnson]

4. ACS - Philadelphia Section Poster Competition

   [2005 – Donna Stauffer
   2006 – Yogi Kurniawan
   2006 – J. Laster, A. Johnson]

5. CHISA 2006 - Prague

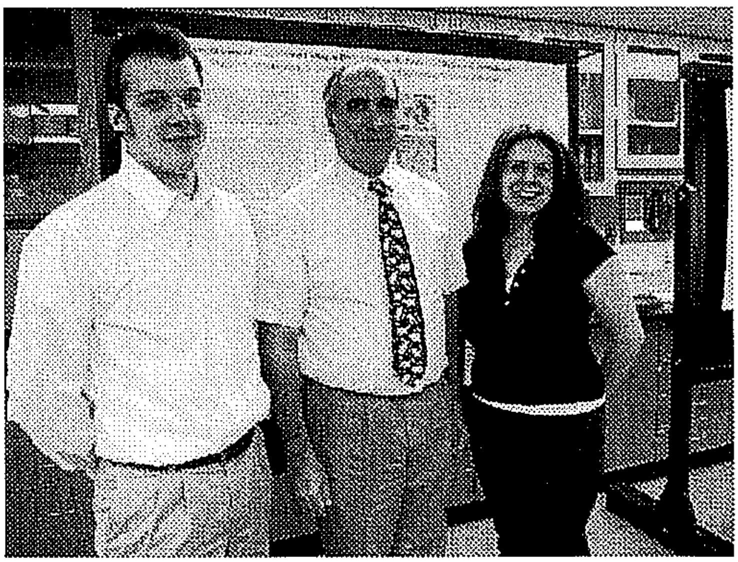
   [2006 – Yogi Kurniawan, J. Laster, A. Johnson
   2006 – G. J. Maffia, M. E. Winkelman]

VI. Preface

The FPRF has funded MBM research at Widener University over the past several years. This research has yielded some significant findings for applications of MBM in the infrastructure as well as some beginning information on higher valued outlets.

Additionally, an undergraduate student has participated in research on the utilization of the lipid portion of the MBM in biodiesel. This student (Brian Coll) has been very successful and has won regional and national awards for his MBM work. Brian won the AICHE National poster competition (Biotechnology Division, November, 2005; Austin, TX) and recently finished third in the AICHE Mid-Atlantic Regional Paper Competition. This student is currently at Widener pursuing a Masters degree; his research is being performed at the USDA-ERRC (Wyndmoor, PA). Brian Coll also lead a group of undergraduate students over the fall ('04) and the spring ('05) semesters in the development, construction and testing of a MBM elutriator and filtration system. This effort was part of a senior design project. This apparatus is an efficient and elegant method of recovering focused cuts of the MBM starting material. Results from this work have been presented (by G. J. Maffia) at the ACS National meeting in San Diego in a session chaired by the USDA.

The MBM effort has been expanded to include a variety of projects all using the second generation of the elutriator – now called the Protein Recovery Unit (PRU). Many of these projects are described in this report.



AICHE National Winners

Brian Coll –
MBM (Various Studies)

&

Megan Winkelman –
Protein Utilization

VII. Recent Scientific Abstracts (2006) – FPRF Projects

International Conference on Solid Waste Management and Technology

PRODUCTION OF BIODIESEL FROM FRACTIONATED MEAT MEAL
Yogi Kurniawan (M. Eng.'06)
Prof. Gennaro J. Maffia (advisor)
Department of Chemical Engineering, Widener University

Abstract
In order to control the accumulation of Meat Bone and Meal (MBM), approximately 1.5 million metric tons in 2003, and the spread of serious potential diseases such as BSE, non-food applications are being investigated. This research examines the conversion of the lipid content of MBM (~ 10% by mass) into biodiesel. A fluidized bed elutriator is used to separate MBM into its constituencies. Transesterification of the fractionated meat portion of Meat and Bone Meal (MBM) to biodiesel and glycerol is achieved by reacting *in situ* with excess methanol using both acid and alkali catalysts. The product sample is washed repeatedly to remove impurities and subsequently dried to obtain the pure new fatty acid methyl ester (FAME, biodiesel) and byproduct glycerol. The biodiesel that is produced is good quality which meets ASTM D-6751-02. Glycerol is easily recovered by decanting and filtration. The remaining solids (mostly protein) have applications similar to collagen and are being tested by the Collagen Research Group at Widener University.

American Chemical Society – Philadelphia Section

MEAT AND BONE MEAL FRACTIONATION AND UTILIZATION
Andrew Johnson, Jordan Laster, and Antoun Mobarek
Prof. Gennaro J. Maffia (advisor)
Department of Chemical Engineering, Widener University

Abstract
Several processing and application technologies for Meat and Bone Meal have been studied over the past two years at Widener University. The goal is to improve the market potential for the nearly 6 billion kg per year of inedible material from animal processing. An elutriation unit operation has been successfully developed, tested and is in current operation. The apparatus consists of an air fluidized bed plus an overhead system for the collection of light (low terminal velocity) material. The elutriation apparatus has been very successful in providing fractions of MBM based on terminal velocity. The value of the various fractions of MBM in infrastructure applications (composites, admixtures, support, and insulation: >$2 B/y potential) specifically regarding asphalt and concrete is being assessed. Given the current fear over BSE, the incentives for such applications are clear. Notwithstanding the issue of BSE, the value of MBM in non-feed applications has economic incentive.

American Chemical Society – Philadelphia Section

BIODIESEL FROM ELUTRIATED MEAT AND BONE MEAL

G. Maffia, Y. Kurniawan
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Abstract

Meat and Bone Meal (MBM), a by-product of food processing, can no longer be recycled through the food chain due to concerns over BSE, commonly referred to as "Mad Cow Disease". Consequently, the disposition of the large supplies of this material is now an environmental and health issue. In this research, a fluidized bed elutriator has been developed to recover fractions of MBM separated on the basis of terminal velocity. The heavier material is the bone which has application as fillers in the manufacture of concrete and asphalt. The lighter material is rich in protein and fats and is processed further. The fat portion of the light cut has been processed *in situ* into fatty acid methyl esters (FAME), referred to as biodiesel. The yields of biodiesel and glycerol have been very good and there is residual protein available for applications as composites or in conjunction with collagen based technologies. Analytical data on the FAME that is produced has indicated properties that are equivalent or superior than biodiesel from other sources.

VIII. Introduction and Background

In order to develop technologies for the improvement of the market potential for the large amount of inedible material from animal production, several processing and application technologies were studied regarding meat and bone meal (MBM). Specifically, the MBM in rendered products was subjected to a similar examination given to collagen from corium by the Widener University Collagen Research Group (CRG). In the past and on a continuing basis, this group has focused on the development of applications for corium that include:

direct infrastructure applications
environmental remediation
artificial tissue
controlled release of immobilized therapeutic medicines.

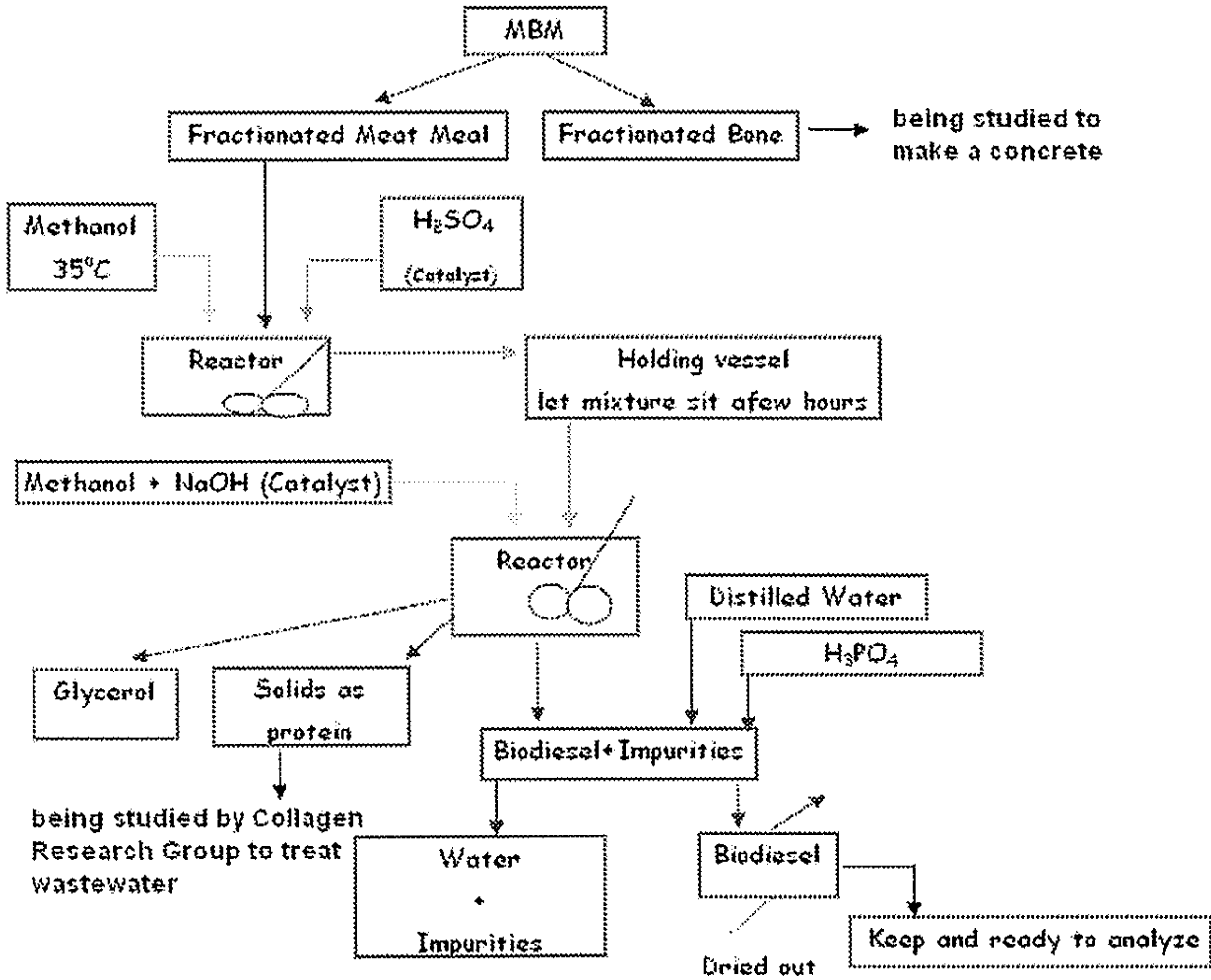
The Collagen Research Group (CRG) at Widener University consists of undergraduate and graduate students, professors from chemical, civil, mechanical and electrical engineering, and colleagues from industry, government and other universities. The group has been in operation at Widener since the early 1990's and has involved about 100 students and professionals. Recently, the CRG has formed research alliances with the Nanotechnology Institute (Southeastern Pennsylvania – a consortium of academic institutions and business organizations) and the United States Department of Agriculture. These alliances have helped in the identification and testing of growth areas for the application of collagen fibrils.

Although the CRG performs some fundamental research, most of the effort has been in the development of new applications for the protein recovered from bovine corium. These applications include environmental remediation, separation and purification, infrastructure, and high value end areas such as controlled morphology matrices of variable geometries for cell growth and controlled release of active agents.

When the CRG first began the studies on bovine corium, it became clear that the initial processing would be the key to the development of applications. Consequently, a strong effort was placed on the development of pretreatment technology to increase the surface area of the material without compromising the chemical and physical properties. Due to the more heterogeneous nature of MBM (than bovine corium), the collagen processing steps were not completely transferable. More front end processing work was required to more fully evaluate the potential of MBM in the higher valued, protein-based applications and well as the high volume, low value applications.

A complete map of the applications for MBM is presented on the following page. The map shows the front end work in general terms and then some details about the suggested processing conditions and the overview of the production of biodiesel.

Widener University MBM Processing Map



<u>Widener Process (MMI) – Neat MM In-situ</u>
Yogi Kurniawan's Biodiesel Experiment
Test Variables

Changing Variables	Fixed Variables	Stage 1	Stage2
-Ratio reactant and catalyst	-Reaction time	2 hours	2 hours
-Volume of neutralizer	-Temperature	35 oC	35 oC
	-Weight of MBM	5 gr	-
	-Stirring velocity	350 rpm	350 rpm

IX. Summary of Work

Currently, the following graduate students are working on the aspects of the MBM project:

Brian Coll (Aug, '06)
Sharmila Rao (May, '06)
Yogi Kurniawan (Aug, '06)
Megan Winkelmann (Aug, '06)

The senior project team of Brian Coll, Justin Miscavige, Jackie Shea and Matthew Bonanno have completed their research and development in May, 2005. This work was presented at Widener during senior projects. As indicated above Brian Coll is continuing this research while in residence at the USDA. Drs. William Marmer and Raphael Garcia have provided material for the Widener research as well as mentoring for Brian Coll.

The following undergraduate students are working on the elutriator design and infrastructure applications, such as, concrete and asphalt:

Andrew Johnson (BS, May, '06)
Jordan Laster (BS, Aug, '06)
Antoun Mobarek (BS, Mayg, '06)

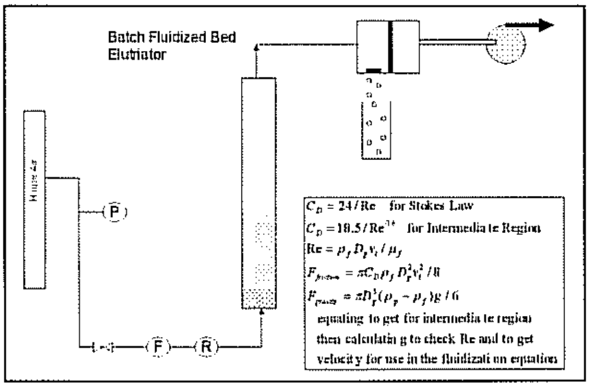
The specific topics assigned to each of the students is listed in the Co-Investigators section (section III) of this report. The following presentations have been given over the course of the FPRF funding cycle that ended in January, 2006.

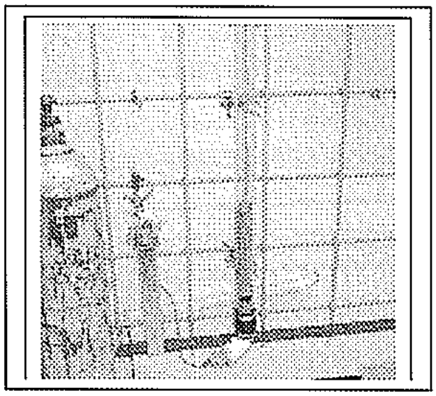
ACS Meeting in San Diego (by G. J. Maffia, March, 2005)
Honors Week (by Brian Coll, April, 2005)
AICHE National Meeting in Austin (by Brian Coll, November, 2004)
AICHE Regional Meeting in Easton (by Brian Coll, April, 2005)
International Conference on Solid Waste in Philadelphia (by G. J. Maffia, March, 2005)

The other presentations that were given in January, 2006 or are upcoming later in the year are listed in the Co-Investigators section of this report (section III).

Elutriation via the Protein recovery Unit (PRU)

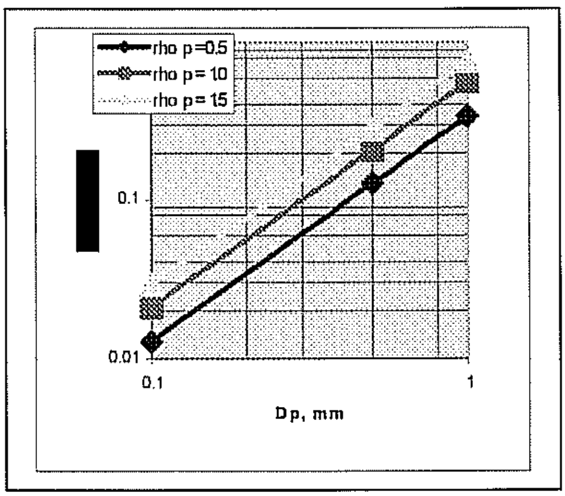
The elutriation apparatus (other photographs presented in Appendix A) has been constructed and is in continuous operation. The device is very effective in achieving the fractionation based on





terminal velocity. A process flow diagram of the apparatus and a photograph of the hardware are presented below. The current apparatus is a second generation device that represents an upgrade with better separation over the original equipment

For spheres the terminal velocity map is shown below. Note that the velocities are significantly different for the different density materials and for the different sizes. This is the incentive for effecting the separation. The initial particle size distribution of the material is shown in the table below and is based on a standard sieving procedure



Sieve No	aperture(in)	mass of material(g)
200	0.0029	**0.2**
120	*0.0038*	**41.8**
100	0.0058	**164.4**
40	*0.0126*	**111.3**
20	0.0328	**60.7**
16	0.0469	**79.9**
10	0.065	**35.8**
8	0.093	**3.2**

The protocols are now being finalized to achieve a certain degree of fractionation. This may involve multi-staging or repeat runs through the PRU.

Objectives and Progress

Consequently, the main objectives of the proposed research and the progress to date are as follows:

1. to coordinate with USDA on using low ash poultry and MBM
   [this will allow the utilization of a more homogeneous material, making it easier to identify the key physical properties that are important for the application of MBM in novel technology]

   progress: USDA is supplying the MBM and poultry meal; a Widener student is in residence at the USDA laboratories in Wyndmoor pursuing his master's degree. Two other graduate students are working with the MBM supplied by the USDA; these students are in residence at Widener.

2. to characterize the physical and chemical properties of the elutriated samples as with collagen characterization

   progress: The elutriator has been built and is in continuous operation. Physical properties of various fractions have been determined. The current goal is to relate these physical properties to the operating protocols of the PRU.

3. to develop the dispersion techniques for MBMPC alone or as a blend with milled bovine collagen

   progress: blending studies are in progress on the elutriated protein portion – the blended sample has lower viscosity (for the same mass of solids) and hence may offer some advantages in the development of other composite technologies

4. to experiment with the neat and the dispersed composite material – [raw and elutriated] in the concrete and asphalt testing devices

   progress: the bulk of this work has essentially been completed – there will be some residual on-going work to further clarify the potential of the individual fractions in concrete and asphalt

5. to study the full range of compositions and physical properties of MBM associated with a given performance in concrete and asphalt building materials

   progress: As above in #4, this work has been nearly completed. The mapping of compositions and performance in infrastructure applications remains to be finished.

Several additional goals and projects have been added to the mix and have been completed or are in progress.

6. to process the meat portion of the elutriated material into biodiesel by in-situ transesterification

   progress: this work has been very successful has been completed. The results have been presented at technical conferences and have been very well received.

7. to use enzymatic treatment to destroy the potential of BSE in raw MBM

   progress: this work has begun by Brian Coll at the USDA and is using the novel enzyme, Versazyme, supplied by North Carolina State University. This work is due to wrap up this semester (Spring, 2006)

Brief Review of Experimental Design

In order to fully evaluate the potential of MBM in the applications that were found to be efficacious for bovine collagen, the following pretreatment steps were studied:

a. elutriate the incoming MBM via the PRU unit operation
b. milling as well as the use of neat (elutriated) material
c. washing, extraction, centrifugation and drying (conventional, vacuum drying and freeze drying will be studied)
d. the analytical testing will be the same as has been performed for the milled corium by the Collagen Research Group. Additionally, the material will have a complete physical and composition work-up as part of the assessment of the performance of the PRU.

Upon full characterization the material was tested in the following applications:

e. infrastructure
    1. admixture for concrete
    2. composite structure with concrete
    3. admixture for asphalt
    4. composite structure with asphalt
    5. composite/reinforcing material for ice based structures
    6. blend with collagen and carrageenan for insulation
f. macroporous matrix development
    1. neat or blended with collagen
    2. testing of the aseptic nature and the ability to grow a variety of cells
    3. controlled release of blended and impregnated materials

X. Results to Date

The full slate of results has been organized and summarized in the Appendix to this report and represent significant achievements by the student researchers in a wide number of areas. Some of this research should be industrially viable and may be of interest to the FPRF members.

The three major accomplishments of this research are:

4. the development of the PRU
5. the demonstration of the improvement in concrete properties upon the addition of 2-5% bone portion
6. the production of biodiesel for the neat, in-situ reaction of the meat portion of MBM

The Appendix is organized as follows:

A. Elutriation Apparatus – Prototype
B. Elutriation Apparatus – Initial Overhead Filtration System
C. Micrographs of Separated Material
D. Protein Recovery Unit (PRU)
E. First Cuts – Bone and Meat Cuts
F. DSC Tests for Elutriated Material
G. Protein Laboratory – Students Making Meat Meal – Collagen Composites
H. Concrete Compositions and Test Cylinders
I. Compression Test Results
J. Biodiesel Samples
K. Biodiesel Reactions
L. Biodiesel Properties
M. Biodiesel NMR Results
N. Biodiesel ASTM Properties

One of the major accomplishment to date on the project has been the development, construction, and continuous operation of an elutriation device (PRU) that will provide terminal velocity fractionated MBM. The apparatus is based on the transport of the lighter (lower terminal velocity) out of the bed and subsequent capture in a filter, equipped with a slide valve. This is believed to be the first time that such a device has been used successfully in this application. The material produced, that is the various fractions of the sample, have well defined physical property differences and well as being visually quite different.

As an example, the bulk density of the light material (that carried over the top) is 0.5-0.55 g/ml and the remaining material in the bed has a bulk density of 0.7-0.75 g/ml. In the previous progress report, velocity and flow performance data has been presented. This information is now being correlated with pressure drop for the various fractions. The monitoring of pressure drop will become part of the operating protocols. Micrographs including measurements of the separated material are shown in the Appendix.

The initial top cut material has 20 % higher protein and nitrogen content than the bottom cut. The bottom cut has a 50% higher ash content than the top cut. The destructive testing has indicated that the bottom fraction that is heavily bone will perform significantly better (30%) in concrete and other infrastructure applications. The lighter material when placed in concrete improves the plasticity but results in material that has lower compressive strength over the time of the testing. A complete mapping of the results correlated with the physical properties of the fraction will be prepared for the final report (at the end of the year).

Analysis of the Animal Byproducts Used in the Study

The Meat and Bone Meal used in the study was supplied to Widener University by the USDA in several lots. The first was a Moyer product and has a typical analysis as follows:

Typical Analysis	**(Mass)**
Dry Matter	92 %
Crude Protein	50.0 %
Fat	9.5 %
Crude Fiber	2.5 %
Calcium	10.1 %
Phosphorus	4.8 %
Total Digestible Nutrients	65.3 %

The second MBM lot supplied by the USDA was used in the elutriation experiments and has the following analysis (next page):

Crude protein (N x 6.25) 51%
Ash 30% (primarily Ca and P)
Crude fat 12%
Moisture 6%

Density (g/mL)
Loose bulk 0.63
Packed bulk 0.67
Absolute 1.48

AA analysis (%)

Alanine	4.23
Arginine	3.49
Aspartic Acid	4.16
Cystine	0.34
Glutamic Acid	6.85
Glycine	7.09
Histidine	1.17
Hydroxyproline	2.62
Isoleucine	1.26
Leucine	3.37
Lysine	2.7
Methionine	0.78
Phenylalanine	1.72
Proline	3.98
Serine	2.02
Taurine	0.1
Threonine	1.65
Tryptophan	0.34

Crude Meat and Bone Meal Analysis

XI. Reflection and Future Studies

The 2006 proposal to the FPRF

The key areas of the ongoing MBM research at Widener University are the pretreatment of the raw MBM (by size fractionation and milling where appropriate) and the assessment of the efficacy of elutriated MBM in infrastructure and higher value applications. From a historical perspective, when the Collagen Research Group first began the studies on bovine corium, a strong effort was placed on the development of pretreatment technology to increase the surface area of the material without compromising the chemical and physical properties. The addition of the elutriator to the processing schema for MBM has increased the possibility for higher valued applications. The fluidization apparatus and the associated instrumentation has been designed, tested and is now in continuous operation for the fractionation of MBM into the constituent-dominated parcels. That is, the protein rich fraction can be recovered overhead and the bone rich material will remain in the bed. The physical properties (size, bulk density, protein content) between the transported material and that still in the bed can be different by up to 50 % in only one stage of operation with no rerun of material. This is a very strong performance for the air fluidizer. The equipment is simple and easy to use and should be a major advance in the identification of markets for MBM.

The subject of the recent proposal to the FPRF is the continuation and expansion of the current effort on the utilization of elutriated material. Specifically, this current proposal requests funding for the support of a graduate student(s) to accomplish the following tasks as part of a Masters thesis project:

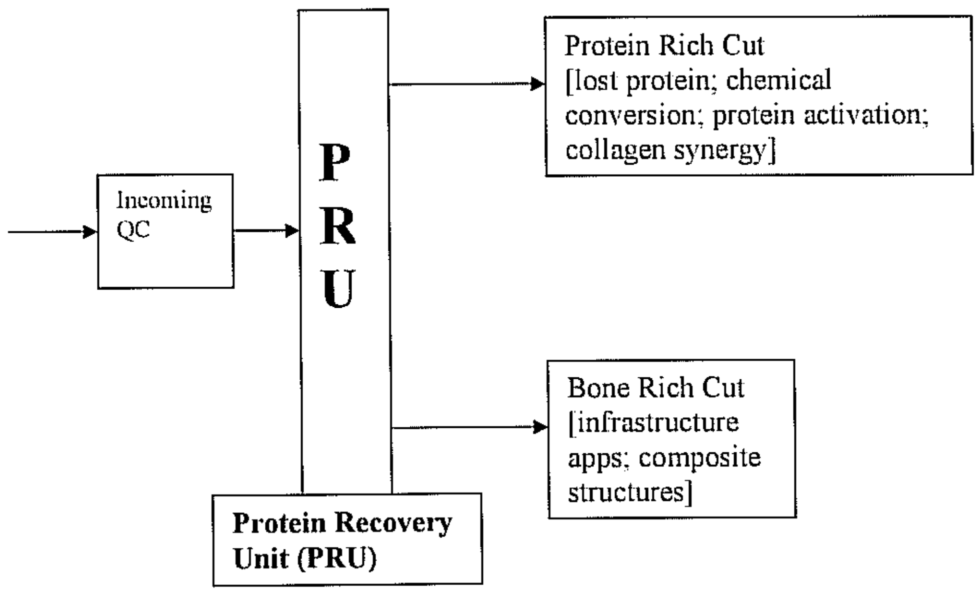
1. codification of the elutriation protocols into a unit operation for the recovery of cuts with specific and narrowly distributed physical properties
2. utilization of the cuts in targeted areas such as the lost protein technique being developed for collagen – this technology has applications in a wide range of industries, the most promising being the manufacture of porous metals for structures and catalyst support
3. using the focused cuts from the elutriator, establish synergy with technologies being developed such as infrastructure options, composites, and biodiesel production
4. development of scale-up parameters for the use of the elutriation technique on a much larger scale
5. development of the technology that would allow the expansion of the fractionated material into environmental remediation markets based on chelation or extraction

Over the past year, undergraduate students (4) and a graduate student worked on developing the fractionation technology for MBM. Thanks go to the USDA for the MBM starting material and help with some of the analyses. One student was in residence at the USDA for the biodiesel work. The work has resulted in a national and a regional award, as well as presentations at regional and national technical society meetings. This student is continuing through a Masters degree at Widener University and is in residence at the USDA.

The planned studies for the 2006 proposal are bolstered by the additional benefit of being able to clearly determine the impact of composition on the applications being studied. Using elutriated material, and having developed protocols for milling, washing, extraction and drying of the material, the value of the protein in MBM in the following major areas are being assessed –

infrastructure (especially as high valued admixtures),
environmental (chelation of metal contaminants in water),
synthesis (lost protein technology for porous macrostructures),
chemical conversion (production of fuels).

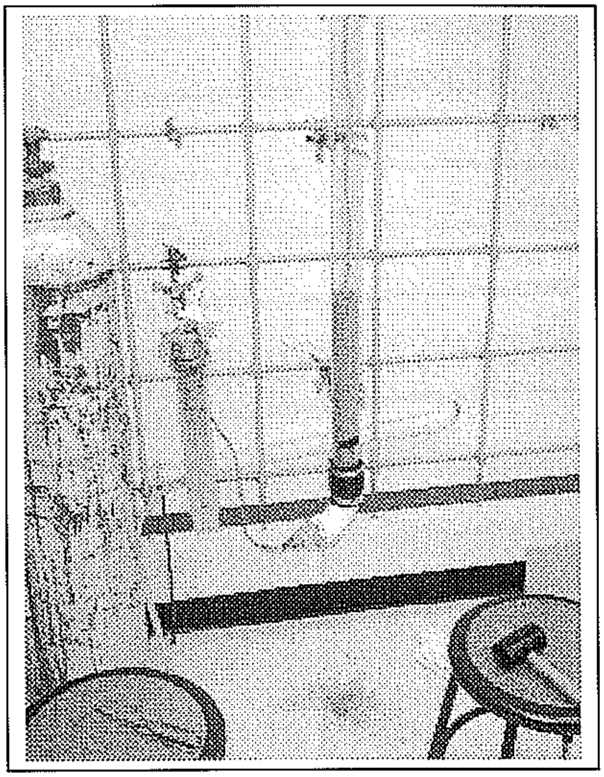
Given the current fear over BSE, the benefits for such applications are clear. Notwithstanding the issue of BSE, the value of MBM in non-feed applications has economic incentive. A processing and applications map is shown below. This summarizes the current proposal regarding the potential processing of MBM.



APPENDIX

APPENDIX A

Prototype of the Elutriation Apparatus – photographs of the rest bed and the inlet system.



Equations for the Terminal Velocity Separation of Particles (equations written for spheres)

$C_D = 24/\mathrm{Re}$ for Stokes Law

$C_D = 18.5/\mathrm{Re}^{0.6}$ for Intermediate Region

$\mathrm{Re} = \rho_f D_p v_t / \mu_f$

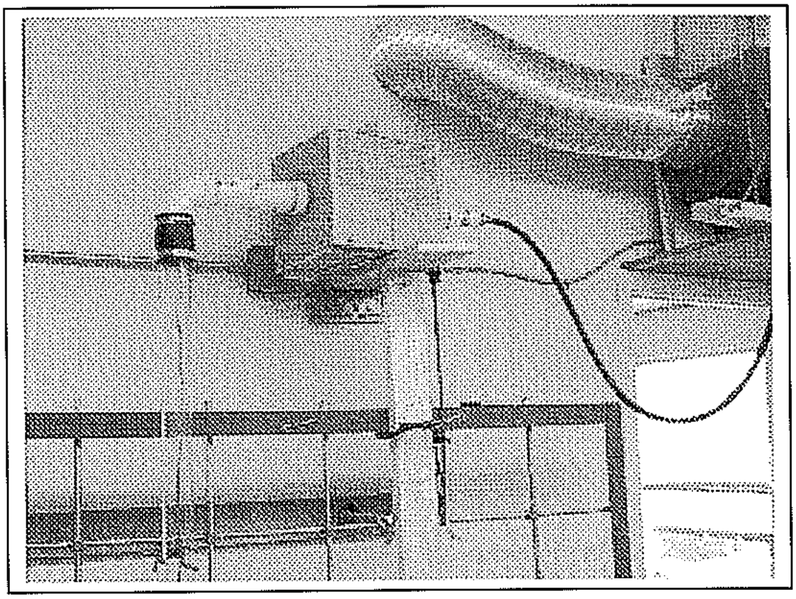
$F_{friction} = \pi C_D \rho_f D_p^2 v_t^2 / 8$

$F_{gravity} = \pi D_p^3 (\rho_p - \rho_f) g / 6$

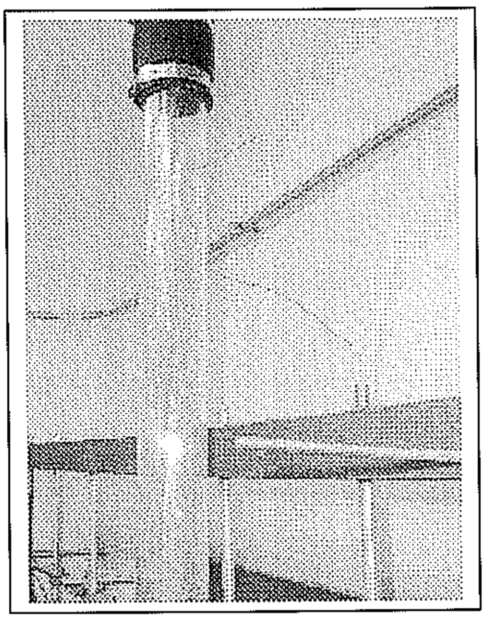
equating to get for intermediate region then calculating to check Re and to get velocity for use in the fluidization equation

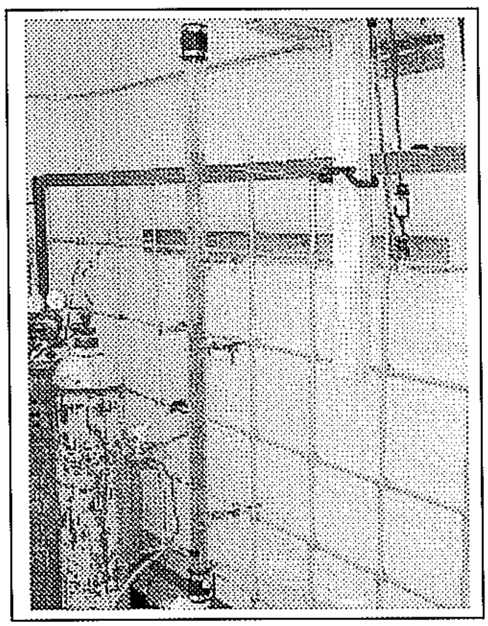
APPENDIX B

Overhead apparatus showing the filter and vacuum system



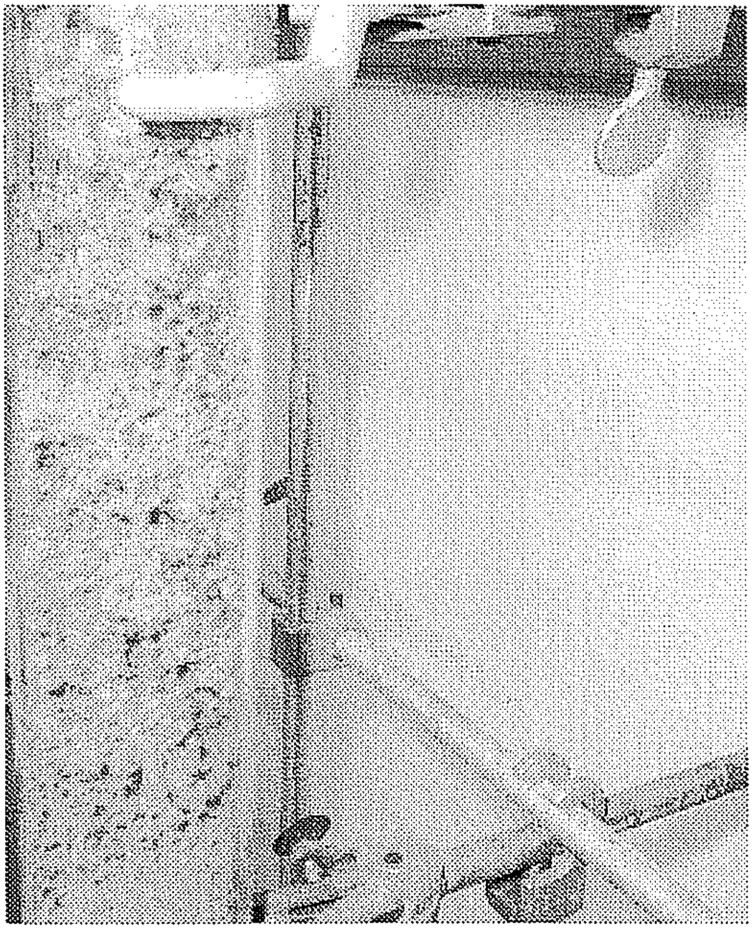
In operation, the light fraction being transported overhead:





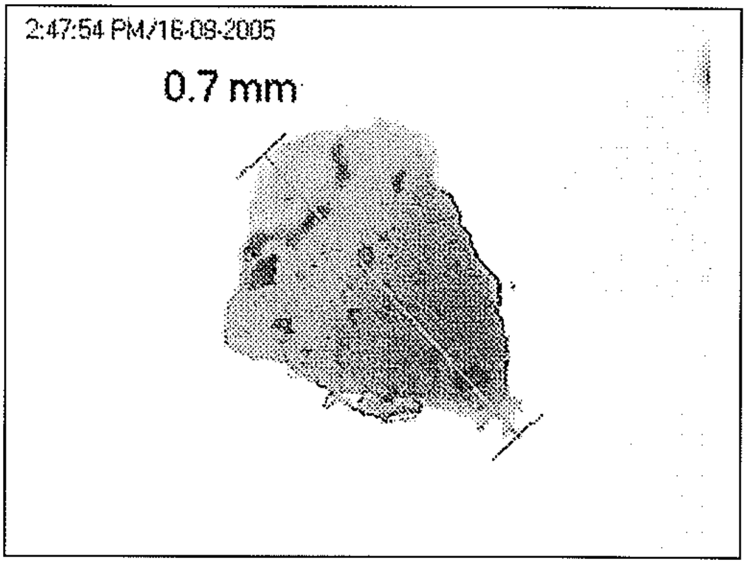
APPENDIX C

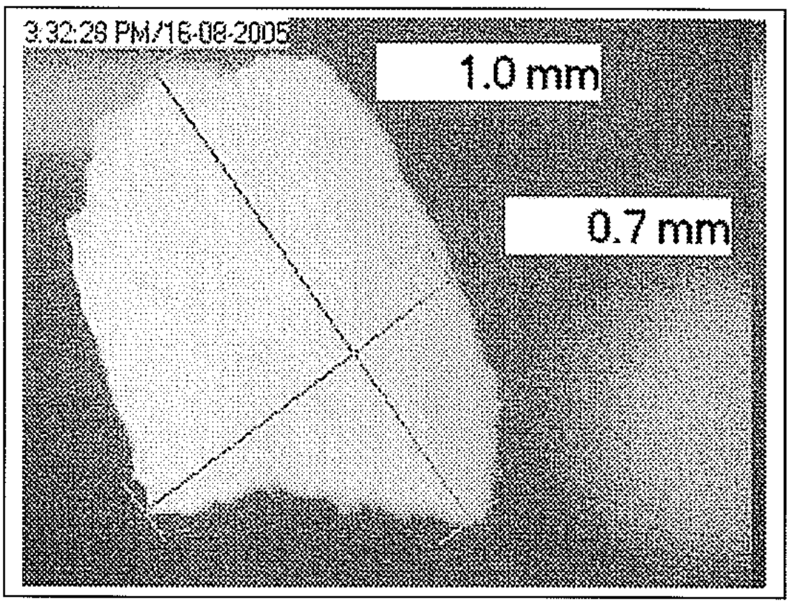
Bed Expansion and Initial Particle Separation



APPENDIX C – Micrographs of Separated Material

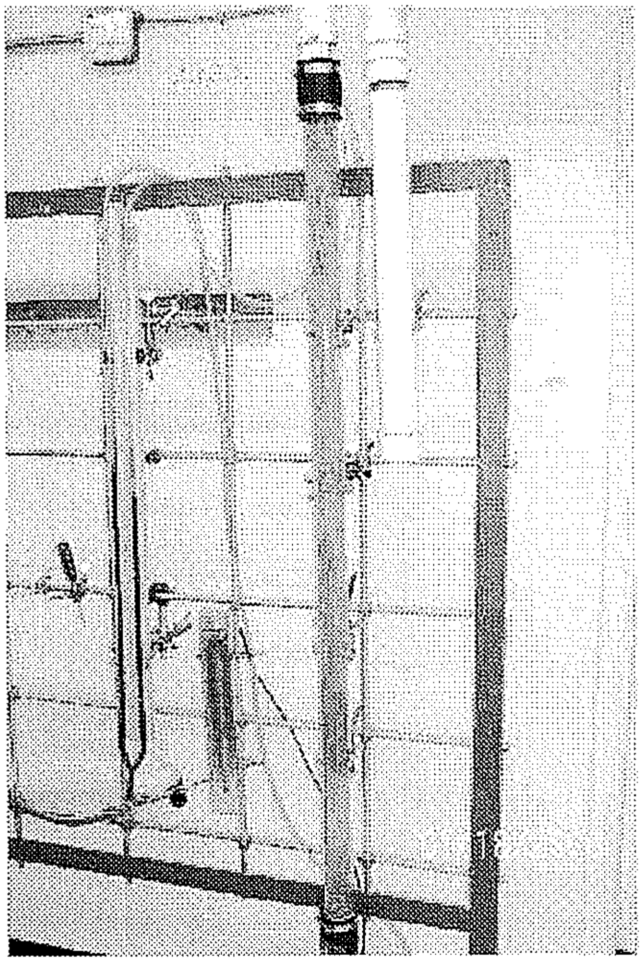
Micrographs of bottoms material (measurements shown):



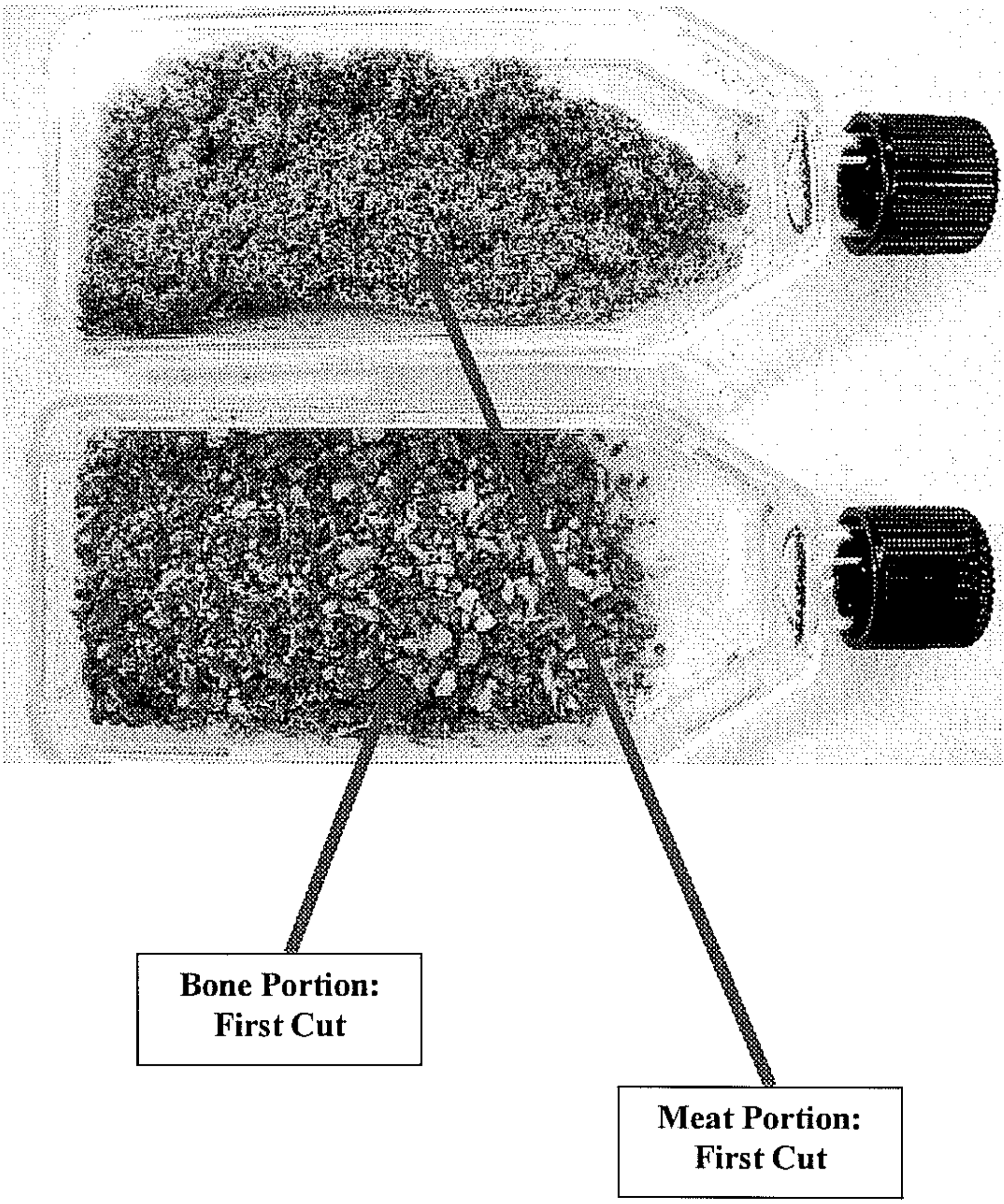


APPENDIX D – Next Generation – Modified Recovery System and Associated Instrumentation

Protein Recovery Unit – Small Scale Apparatus

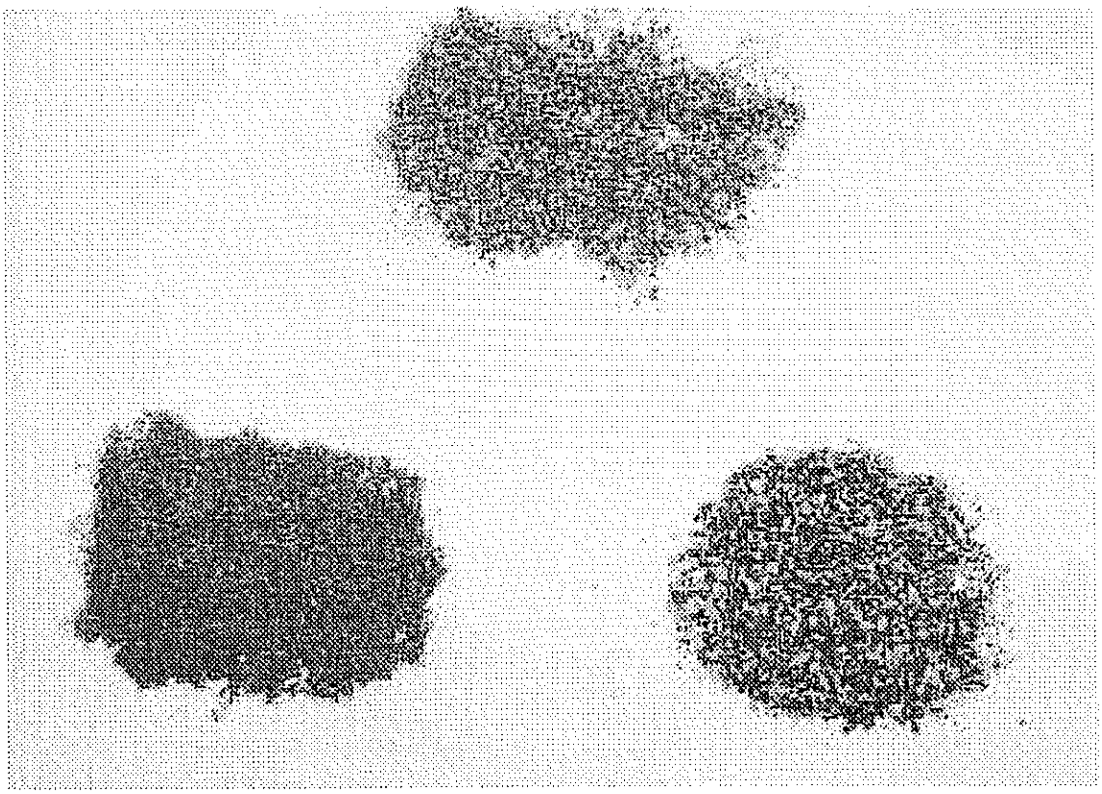


APPENDIX E – First Cuts (Bone and Meat Cuts)



APPENDIX E – First Cuts (Bone and Meat Cuts), ...

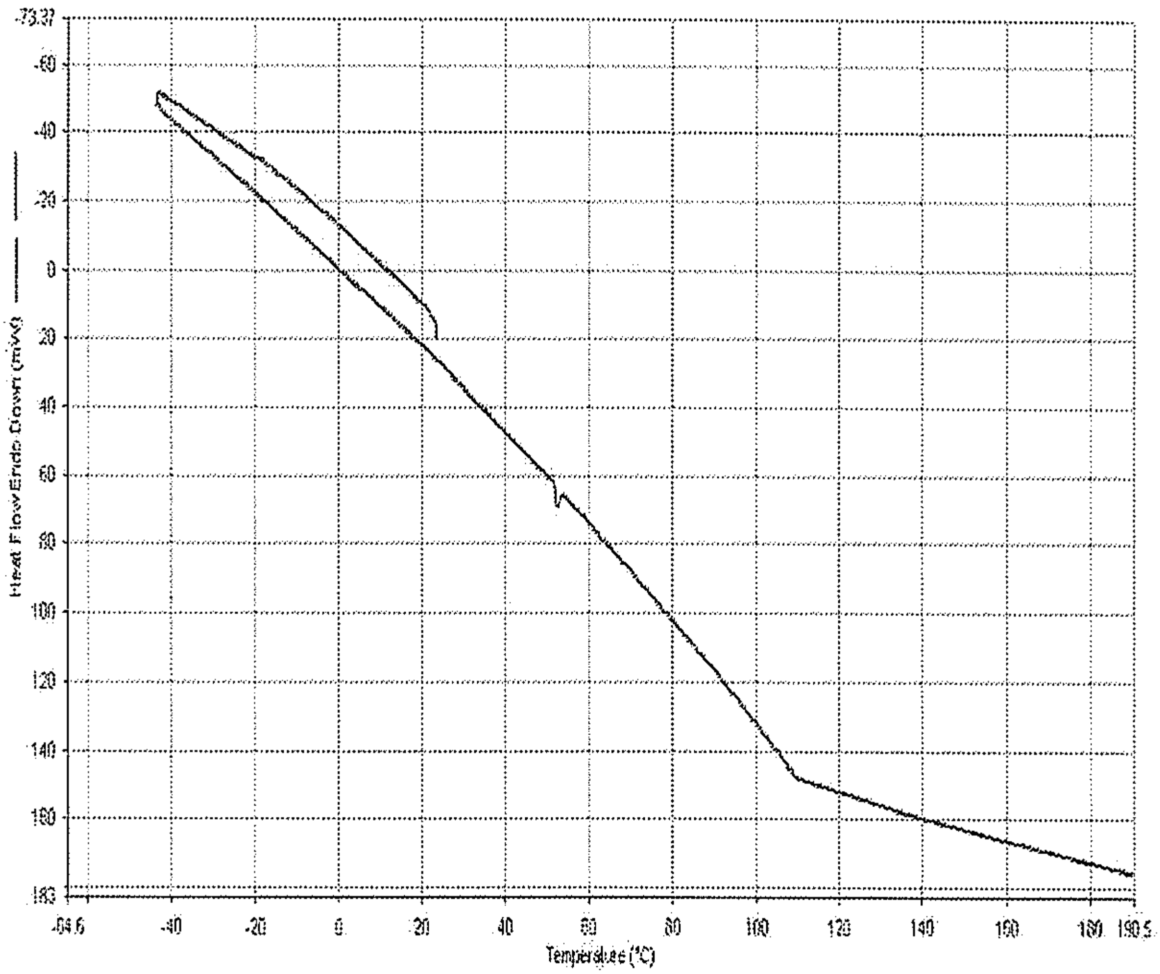
continued



APPENDIX F – Differential Scanning Calorimetry for the Top and Bottom Cuts of the Elutriated Material

Differential Scanning Calorimetry of Fractionated Meat and Bone Meal

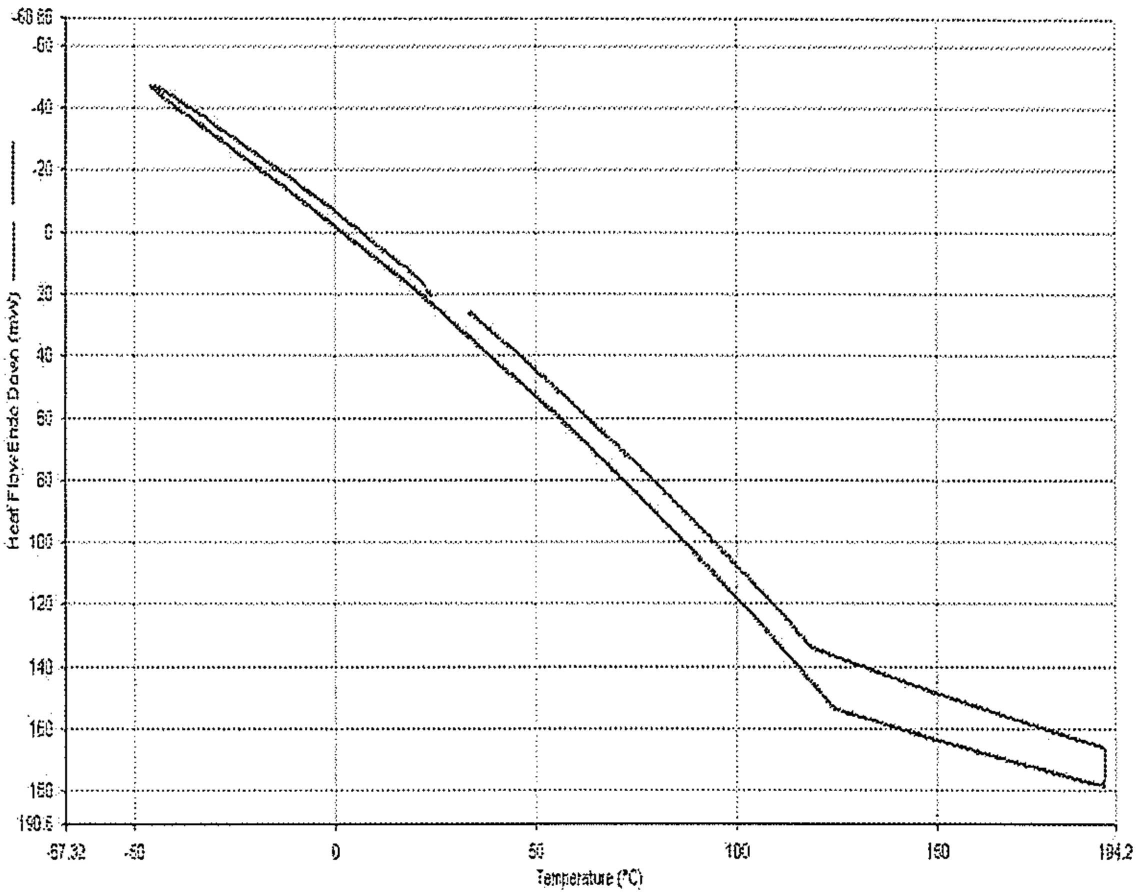
Meat Portion



APPENDIX F, ... continued

Differential Scanning Calorimetry of Fractionated Meat and Bone Meal

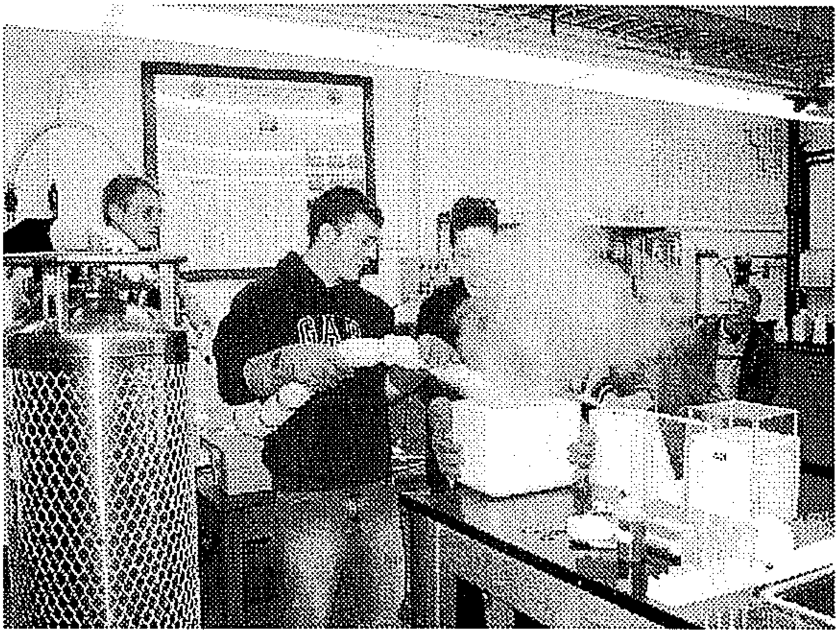
Bone Portion

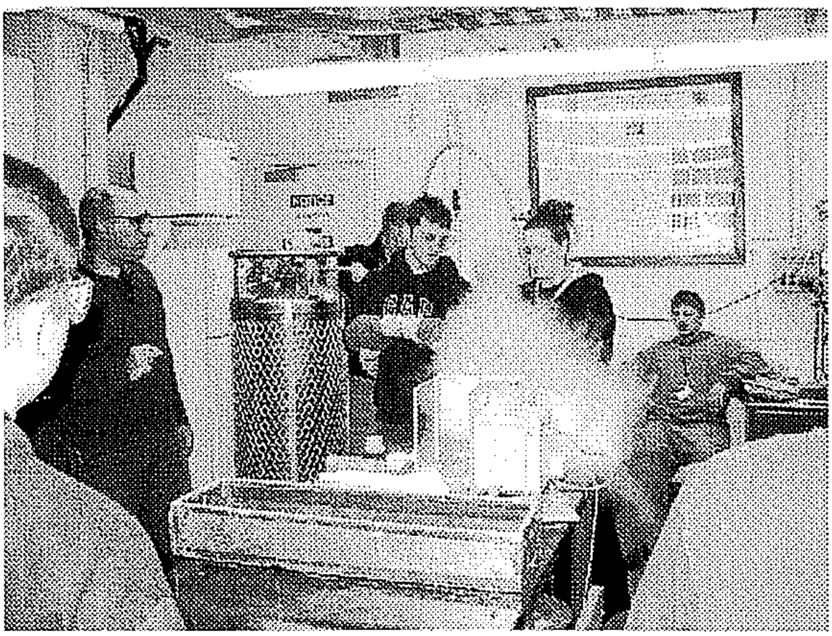


APPENDIX G

Protein Laboratory – Students making Meat Meal – Collagen Composites Using Liquid Nitrogen for Droplet Freezing

Students Preparing Collagen/Bone Meal Composites

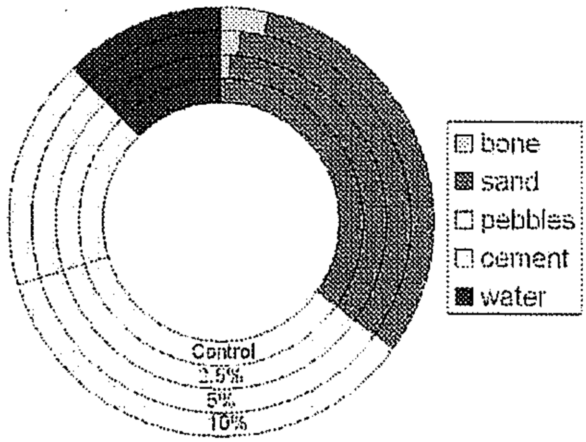




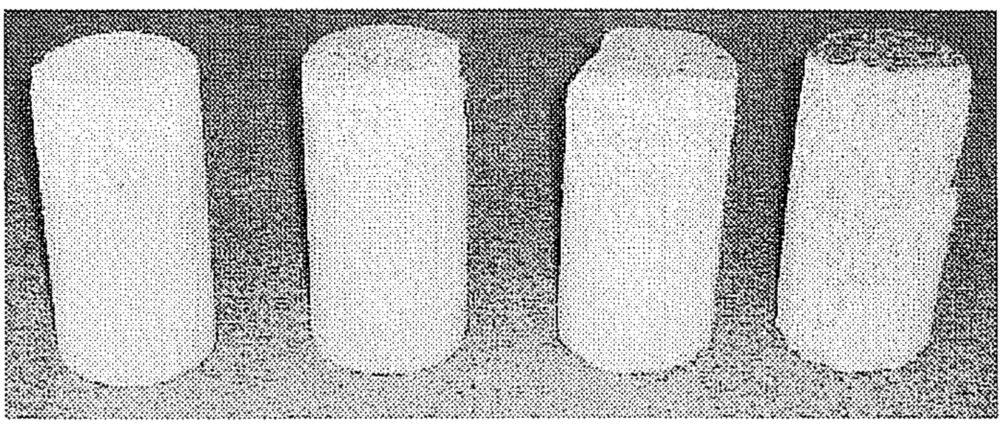
APPENDIX H

Concrete Compositions and Test Cylinders

Concrete Compositions



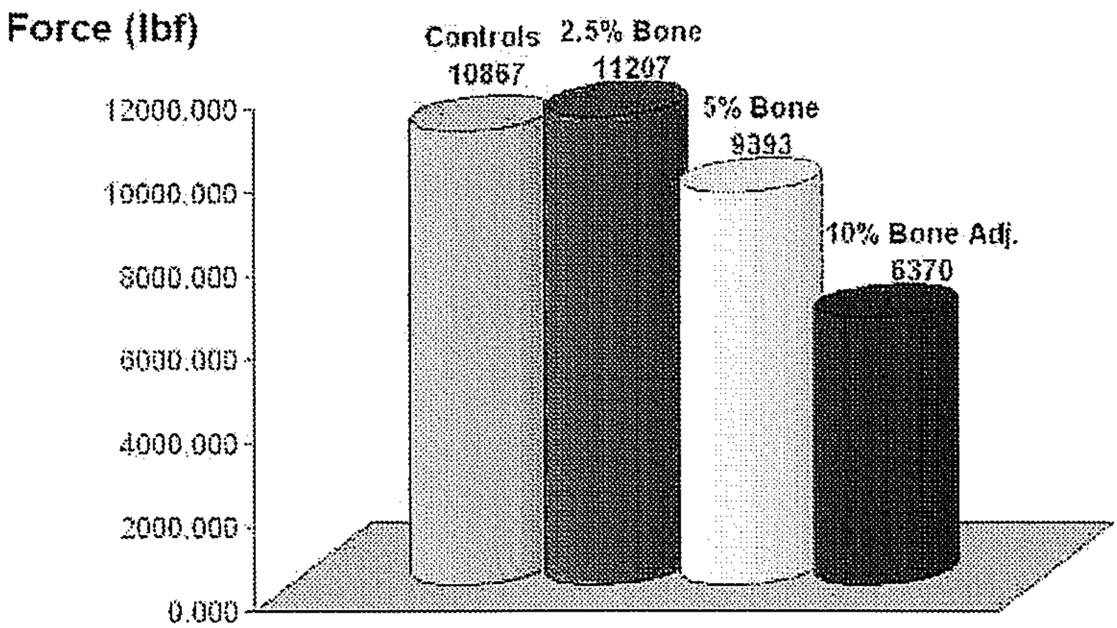
Test Cylinders



Control 2.5% 5% 10%

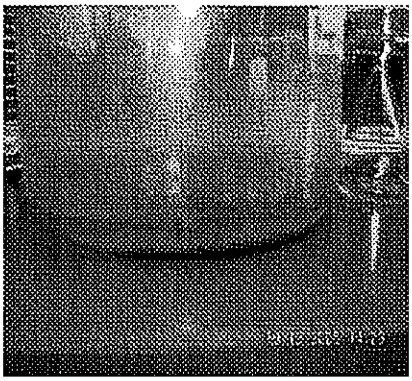
APPENDIX I

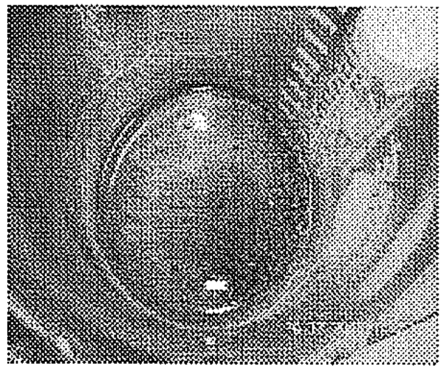
Compression Test Results

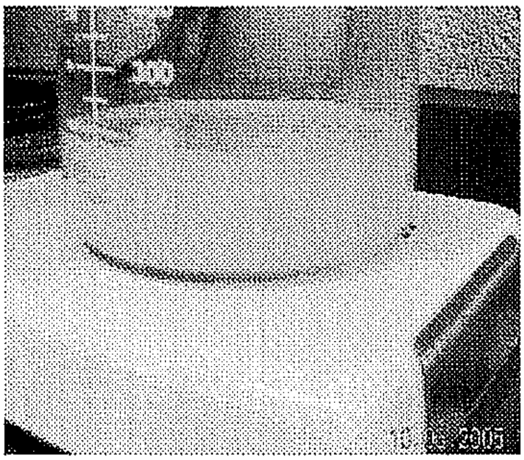


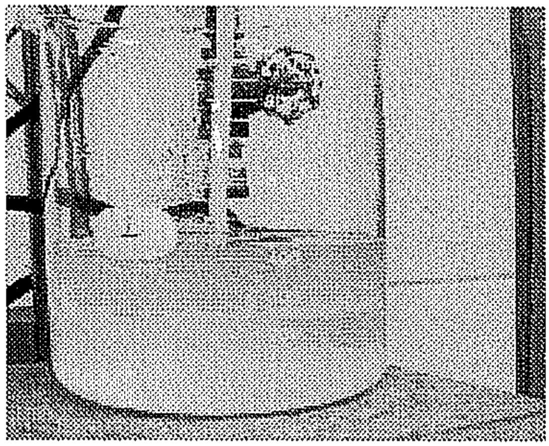
APPENDIX J

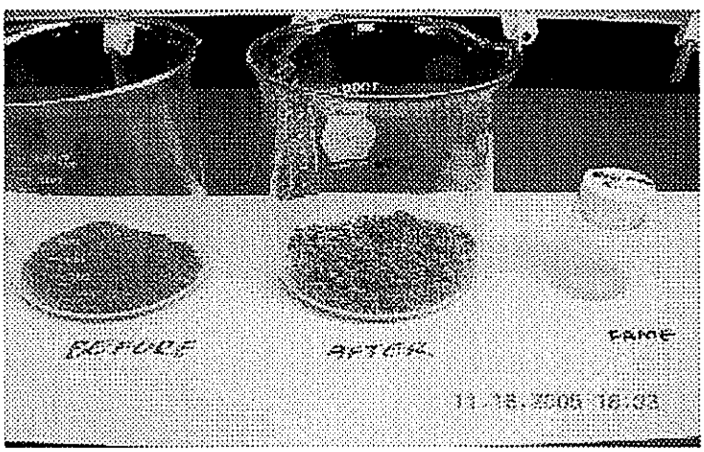
Biodiesel Samples and Processing





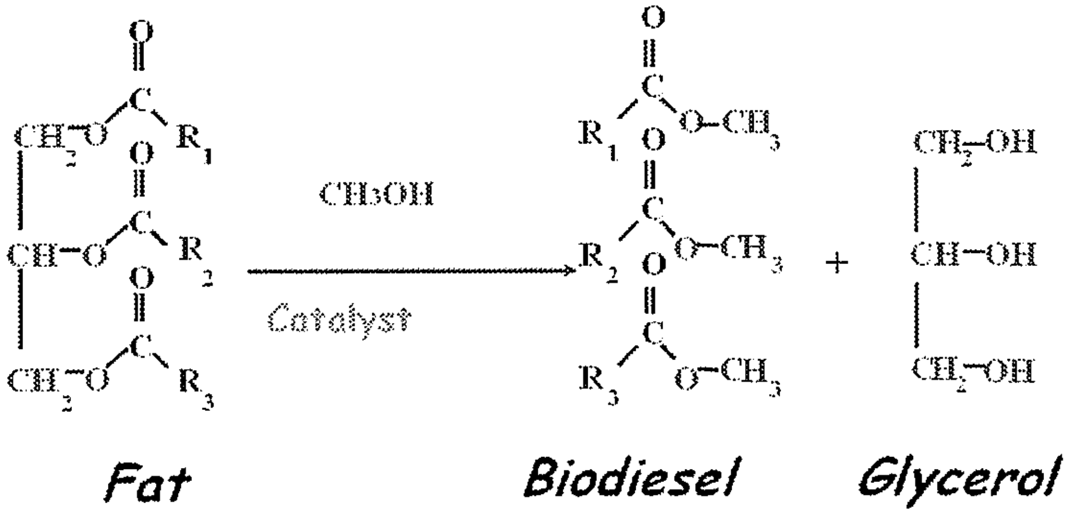






APPENDIX K

Biodiesel Reactions



The transesterification of MBM was successfully performed with good quality that meets ASTM D-6751-02. This method is an effective way to produce fatty acid Methyl Esters (FAME) as biofuel. After the biodiesel reaction, soild left is as protein that is being investigated to treat wastewater by Collagen Research Group at Widener University. Bone fraction which was nearly 1/4 mass on MBM could be used to make concrete.

APPENDIX K

Biodiesel Production Procedures and Biodiesel Properties

1.Remove bone chips from MBM
2.Weigh MBM (bone chips free) and put into beaker glass
3.Pour 40 ml of methanol, heat to 35oC
4.Add 0.03 ml~1 drops of concentrated sulfuric acid
5.Mix gently at low rpm
6.Maintain the temperature for 1.5 hour then stop the heat
7.Mix for 1 more hour
8.Mix sit for 8 hours
9.Dissolve 80 mg of NaOH into, 40 ml of methanol
10.Pour half of step (8) into the mixture (7)
11.Heat the mixture to 35 oC and maintain
12.Add remaining step (9) into the heated mixture stir at low rpm
13.Stop stirring after 2.5 hours, allow the mixture to settle for afew hours
14.Separate the solid reactant which is on the bottom
15.Neutralize the supernatant with H3PO4
16.Recover the ester in a bottle and wash with water
17.Decant the water
18.Dry and store the fuel
19.Analyze the quality of biodiesel and observed the color over time

PROPERTIES	**Biodiesel MBM**	**ASTM D-6751-02**
Kinemcatic viscocity m2/s, 40 oC	1.91E-06	1.9-6 x 10-6 m2 /s, T = 40oC
Acid value	0.1	0.8 max
% Glycerol	0.07%	0.24 max

APPENDIX M

Biodiesel NMR Results