**NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY**

**Faculty of Industrial Technology**

**Department of Industrial and Manufacturing Engineering**

**Final Year Project [TIE 0000]**

***Design***

***o***

***f***

***a***

***Mould Temperature Control System***

***f***

***or Optimi***

***s***

***ation***

***of***

***Injection Moulding Temperature Control***

**Khulumani Khuluma**

**N0141000Z**

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**Supervisor:**

**Eng. S**

**SSS**

**MAY 2014**

**BULAWAYO**



***Submitted in partial fulfilment of the requirements for***

***the***

***Honours***

***Bachelor of***

***Industrial and Manufacturing Engineering***

***Degree***

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# DEDICATIONS

This project is dedicated to my family especially my mother and father.

# ACKNOWLEDGEMENTS

It is with great honour and privilege to have travelled this far in the quest for knowledge with the Lord God on my side throughout. Many persons have given their utmost support and encouragement and the few names singled out here represent all those whose input built the foundation and were the corner stone of this work.

Many thanks go to Mr X. Xulu, project supervisor and lecturer, whose guidance and dedicated support cannot be overemphasised.

Special gratitude goes to my parents Mr and Mrs Xoxo, for their untiring support throughout the period of research and compilation of this project.

My appreciation goes to the staff at the Mechanical Workshops for their valuable input.

Great appreciation and thanks go to my colleagues for their assistance and support during the research times.

# ABSTRACT

The thermodynamic dependency nature of Injection moulding has made mould temperature control an important aspect of its success as a globally recognized manufacturing process. Injection mould temperature is important in the filling of polymer melt in the mould cavities during part formation. Monitoring and control of the desired mould temperature has a significant effect on the product quality, energy usage and raw material-product conversion of any injection moulding process. The project presents an injection mould temperature control system that uses a Multi Agent system developed in Java Agent Development Framework (JADE). Key system parameters and their effects on mould temperature and the process as a whole are investigated experimentally; a relationship is developed and applied as part of the basis of the temperature control function. A control system is developed in BARIX using a Barionet100 logic controller to facilitate in system monitoring and control, to enable the system to respond effectively and swiftly to changes in input parameters and minimize fluctuations from the required moulding conditions. The JADE agents monitor input parameters, communicate and make computation based decisions on the actual mould temperature, temperature difference from the set mould temperature to determine the power supplied during heating and heating time as well as the cooling time required for system conditions at any given time. The effectiveness of the control process is achieved through synchronized utilization of the Barix control logic and the JADE Multi Agent System.

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# CHAPTER ONE - INTRODUCTORY CHAPTER

## 1.0 Introduction

Towards the end of the 20th century, global focus had become on the growing concerns of global warming, the emphasis being on the development of environmentally friendly manufacturing processes and products, (Peattie & Charter, 2003). Plastics processing was therefore identified as a process that adhered to the requirements as it brought forward the development of renewable/recyclable products which are in essence less adverse on the environment than most processes. This project focuses on the development of a modified improved design of a mould temperature controller. Monitoring and controlling mould temperatures as the molten resin traverses in the mould cavities and is converted to a solid part has a large effect on the performance, quality and durability of the resultant part.

## 1.1 Background

*(Gives a general background to the problem)*

A mould water heater is a heat exchanger used to supply heated water into a mould. Although in most cases the idea is to supply cold water to aid in plastic resin cooling, heated water is fed into mould water channels to aid in smooth flow of the molten plastic as it traverses into the mould cavities before cooling. In certain moulds the need for such a device is important for proper part formation; otherwise production would fail ultimately due to miss-runs.

## 1.2 Aim

To design a Mould temperature control system that realizes its function by the use of intelligent agents as decision making support systems.

## 1.3 Objectives

1. To design Taguchi experiments in order to develop optimum operating ranges for the control parameters.
2. To design a Multi-Agent system to aid in the decision making during the temperature control
3. To write the BCL and HTML code to control the system, the application user interface and monitoring the system inputs to control the system
4. To select a valve for the cooling side of the system, to enhance the performance based on flow rate.

## 1.4 Scope

*(Gives limit of study/research, i.e. where research will start and where it will end).*

The project is restricted to the development of a Multi-Agent system based on Java Agent Development Framework; develop the Barix program and selection of a solenoid valve, as well as heating system elements.

## 1.5 Justification

*(Gives the reason why the project has to be done)*

Good control of plastic melt temperature for injection moulding is very important for reducing operator set up time, ensuring product quality and preventing thermal degradation of the melt. The controllability of the set points and other process parameters also depends on the precise monitoring and control of the melt temperatures. (Dubay, et al., 1997).

An effective means for controlling temperatures on temperatures zones during the injection moulding process requires the application of a Model Predictive strategy in a Multiple-InputMultiple-Output scheme, (Dubay, 2002). The implementation of decision making Agents can aid in the improvement of the level of accuracies achieved as well as the deviations from set values during operation by implementing more robust control architecture as they recognize the benefits of MIMO MPC architecture. The concepts of direct cooling can be applied in the new improved design by the use of a proportional valve to execute the cooling behaviour depending on the temperature range between the set and actual values.

## 1.6 Methodology

*(Gives the**research methods used)*

In doing research, the following research techniques will be used:

1. Gathering data from primary sources through observations as the machine was being operated
2. Reviewing company documentation to develop an analysis of the problem iii) Literature review
3. Secondary information used in the review was developed from mainly journals, internet, hand books, eBooks and books.
4. Design of Experiments (DOE): Key parameters involved in the injection moulding process will be selected. These parameters will then be used as factors in the Taguchi experiments.
5. A mathematical model of the experimental results will be developed and used as a basis for the control operation. The overall hardware design will be generated to support the overall operation of the system.
6. Development of a Multi Agent system based on Java Agent Development

Framework(JADE) viii) Fabrication/Building of Hardware System

## 1.7 Timeline

*(The important step in completing your project is to pull together a Project Timeline. This timeline should not only consist of a schedule for completing the project, but should identify important milestones, deadlines, and the resources needed along the way).*

|  |  |
| --- | --- |
| PROJECT START  MILESTONE 1  MILESTONE 2  MILESTONE 3  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24  25  26  27  28  29  30  31  01  02  03  04  05  06  07  08  FRI  SAT  SUN  MON  TUE  WED  THU  FRI  SAT  SUN  MON  TUE  WED  THU  FRI  SAT  SUN  MON  TUE  WED  THU  FRI  SAT  SUN  MON  TUE  WED  THU  FRI  SAT | |
|  | Nov 2014 |

*Fig 1.1 Project Timeline*

#### *Table 1.1 Scheduled timeline*

|  |  |  |  |
| --- | --- | --- | --- |
|  | ENTER START DATE: | 10/10/2014 |  |
|  |  |  |  |
| ACTIVITY | START | END | NOTES |
| Project Start | 10/13/2014 |  |  |
| Milestone 1 | 10/23/2014 | 10/26/2014 |  |
| Milestone 2 | 10/24/2014 | 10/27/2014 |  |
| Milestone 3 | 10/29/2014 |  |  |
| Milestone 4 | 11/8/2014 | 11/10/2014 |  |
| Milestone 5 | 11/18/2014 | 11/20/2014 |  |
| Milestone 6 | 11/28/2014 | 11/30/2014 |  |
| Milestone 7 | 12/8/2014 |  |  |
| Milestone 8 | 12/18/2014 | 12/20/2014 |  |
| Milestone 9 | 12/28/2014 | 12/30/2014 |  |
| Milestone 10 | 1/7/2015 | 1/9/2015 |  |

## 1.7 Summary

*(Gives the summary of the chapter)*

This chapter has introduced the project as a whole. The system was introduced as well as the research work to be carried out entailing the experimental techniques to be employed and the resources for the research. The author went on to the project justification of the project as well as the background information. The aims, objectives, methodology and scope of the project were also outlined. The methodology outlines the path to be followed as a guideline to be followed throughout the project. It outlines the steps that will lead to the modelling and development of the system.

# CHAPTER TWO – LITERATURE REVIEW

*(Looks at available literature related to the particular subject and the sources of such literature. Only the literature to be used is required in order of objectives. See example below).*

## 2.0 Introduction

What is Literature Review? Literature review is a critical analysis of a segment of a published body of knowledge through summary, classification, and comparison of prior research studies, reviews of literature, and theoretical articles, (Choi, et al., 2012). It provides an excellent starting point for researchers beginning to do research in a new area by forcing them to summarize, evaluate, and compare original research in that specific area, ensuring that researchers do not duplicate work that has already been done. This chapter therefore gives an insight of the use of programmable logic controllers and intelligent agents and justifies their use in High Density Polyethylene (HDPE) injection moulding mould temperature control optimization. The author will highlight the current trends in temperature control and the short falls of the existing strategies. The author intends to derive the thrust by which the existing strategies can be further developed by application of new technologies and methods.

## 2.1 Theory of Injection Moulding

According to Shin & Park (2013), injection moulding is one of the most commonly used manufacturing processes for the fabrication of plastic parts in net shape with excellent dimensional properties. The mould, usually made up of two halves is clamped into position before molten resin is injected in at high pressure. After the solidification process, the mould opens and the moulded part is ejected out (Whale et al., 1995). In this way, injection moulded parts have found their way into extensive applications in the packaging industry, household appliances, transport containers, furniture, construction as well as automotive and aerospace industries (Yang & Gao, 2006).

## 2.3 Summary

The chapter has given an overview of literature in relation to the development of the dissertation. The author outlined the processing window in injection moulding, moulding polymers and their behaviour under different conditions as well as related to the injection moulding cycle. The author also looked at the different types of mould temperature controllers in application and their limitations in meeting the complex requirements of the injection moulding process. Sensors, valves and controllers were also looked at to develop an understanding of these components as they will be applied in the design.

# CHAPTER THREE – EXPERIMENTAL SET UP AND DESIGN

## 3.1 Introduction

1. Questionnaires, survey
2. Experimental design and set up

## 3.8 Summary

# CHAPTER 4 - SYSTEM DEVELOPMENT

*(This the real work of the student in developing the solution to the identified gap, student to include a flow diagram)*

## 4.0 Introduction

In his chapter the author will focus on determining the optimum process parameter setting for injection moulding parameters, with the main emphasis being on the effect of mould temperature. Taguchi‘s approach will be used to design the experiment used in investigating the effect of mould temperature on the filling behaviour of an injection moulded part. The results of the experiments will be analysed on Minitab software and on Autodesk Mould flow Advisor. The chapter will also highlight the development of intelligent agents in JADE as well as the Barix code.

## 4.1 Taguchi Experiments

Many factors/inputs/variables must be taken into consideration when making a product, especially a brand new one, (Dicken, (2003). The Taguchi method is a structured approach for determining the ”best” combination of inputs to produce a product or service “Based on a Design of Experiments (DOE) methodology for determining parameter levels”. DOE is an important tool for designing processes and products. A method for quantitatively identifying the right inputs and parameter levels for making a high quality product or service Taguchi approaches design from a robust design perspective.

### 4.1.1 Experimental Procedure

Taguchi‘s design of experiments methodology was employed in carrying out the experiments. The experiments will be performed on site at Mega Pak Zimbabwe Pvt. Ltd. on an Engel DUO 16050/1000 injection moulding machine, running production on the Light Weight Coke crate mould (ZA 4228).

##### Step 1: Problem identification

The first step is the problem identification step. This step involves the identification of the main objective of carrying out the experiments. The objective is to improve mould filling behaviour to minimize the production of short shots and/or related rejects.

##### Step 2: Brainstorming session

The main objective here is to identify key process parameters that affect the injection moulding process. These factors are classified into Control factors and Signal factors. Two sets of experiments were carried out to using different parameters. In Experiment 1, the effect of injection parameters on filling behaviour was investigated with the 5 factors (injection pressure, injection speed, melt temperature, switch over value and mould temperature) being varied over 2 levels.

**4.1.2 Experiment 1: Effects on Injection Moulding Parameters on Mould**

**Filling Behaviour**

Experiment focused on determining the effect of injection moulding parameters on the weight of a moulded part. The weight was chosen as the measuring characteristic as it is indicative of filling behaviour for a crate. The process parameter settings that were applied are as shown in Table 4.1:

#### *Table 4.1: Process parameter settings for Experiment 1*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Level** | **Injection**  **Pressure** | **Mould temperature** | **Melt**  **Temperature** | **Switch value** | **over** | **Injection**  **Speed** |
| 1 | 175 bar | 35°C | 230°C | 60mm |  | 60mm/s |
| 2 | 208 bar | 60°C | 260°C | 75mm |  | 87mm/s |

### 4.1.6 Results for Experiment 2: Effect of Mould Cooling and Heating on Mould Temperature

The results for experiment 2 (Effect of mould cooling and heating on mould temperature) indicate the effect of polymer melt temperature (P1), chilled water (P2), heated water (P3) on the mould temperature for a particular mould region. Trial 1, Trial 2 and Trial 3 document the measured mould temperatures at the different set points as the parameters are varied over the set levels and are shown in Table 4.8 below.

*Table 4.7: Experiment 2: Effect of mould cooling and heating on the mould temperature*

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Expt | P1 | P2 | P3 | Trial 1 | Trial 2 | Trial 3 | Mean | SN  Value |
| 1 | 230 °C | 8°C | 30°C | 35.6°C | 35.5°C | 35.6°C | **35.57°C** | **31.0208** |
| 2 | 230°C | 10°C | 45°C | 43.8°C | 43.7°C | 43.8°C | **43.77°C** | **32.8229** |
| 3 | 230°C | 15°C | 60°C | 55.4°C | 55.4°C | 55.6°C | **55.4°C** | **34.8806** |

## 4.2 System Architecture

The Mould temperature control system will be as defined by Figure 4.15. The system will be enabled by sensors to collect plant data and convert it into logic via the Barionet aided by the decision making system and relayed out to the output devices to initiate actions. The actions will include the manipulation of solenoid valves and relays to pass forward the cognitive action to the conditions in the plant (mould) in a bid to keep the actual mould temperature at par with the actual temperature. V1, V2 and V3 are the solenoid valves used in the system whilst E1 is a centrifugal pump.

## 4.3 Costing Development

Give an account of the total manufacturing cost, that is, the cost of labour and materials required to produce the product.

## 4.4 Summary

The Chapter has given an outlook on the system development from the experimentation phase with Experiment 1 and Experiment 2 determining the effects of mould temperature on filling behaviour and chilled water temperature melt temperature and heated water temperature on mould temperature. The development process of the objective function, JADE agents and Barix control logic was carried out. A selection process for the heating elements, sensors and control valve was documented and subsequent work will be carried out in Chapter 5

.

# CHAPTER FIVE - RESULTS

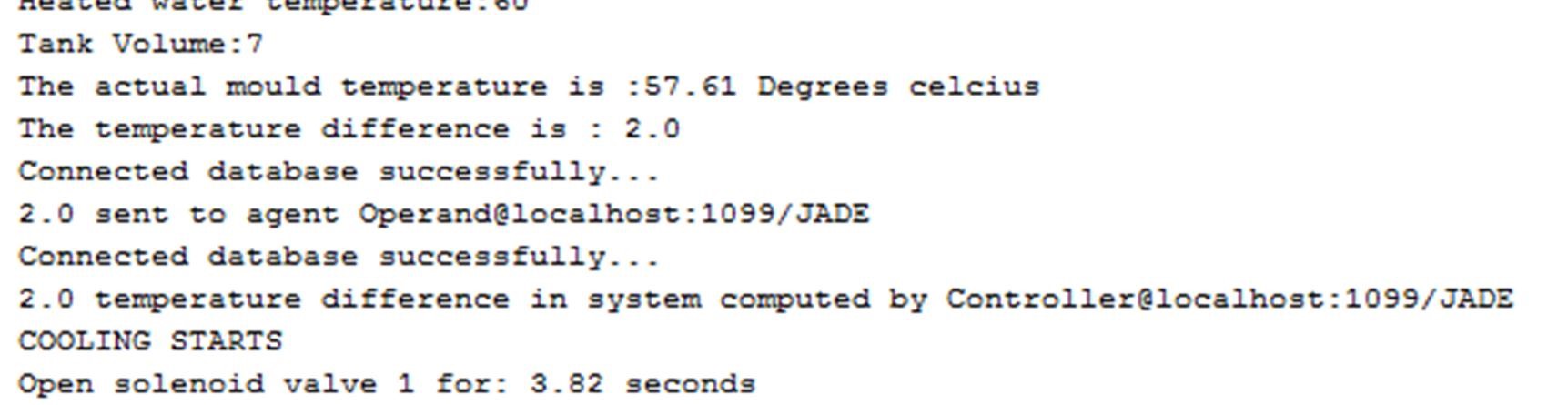
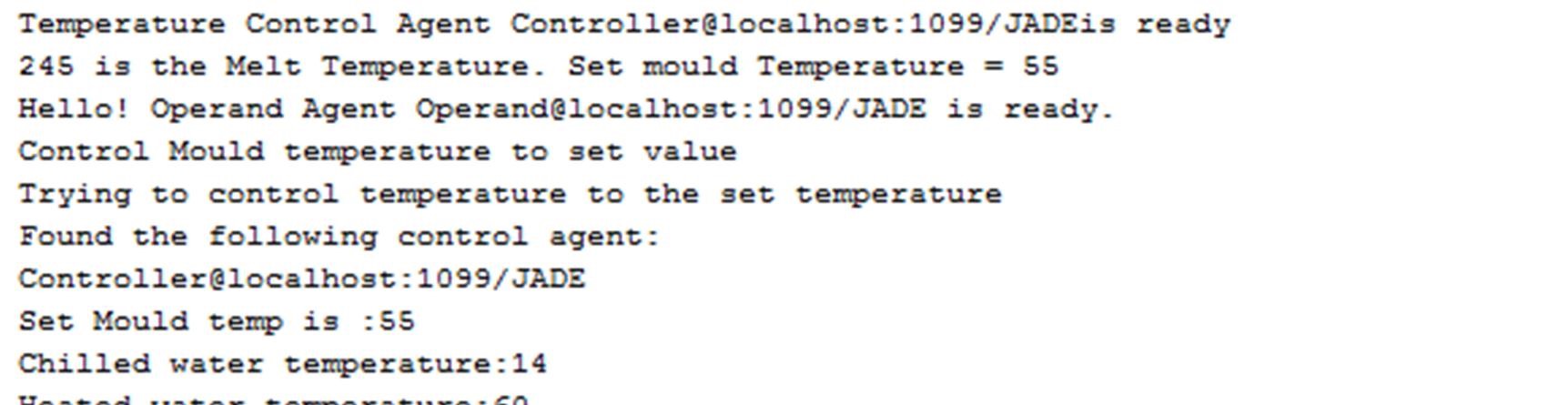
(This gives the results of the research and development done in Chapter Four. An assembled drawing, if it’s a design project, of the component is required or the programme for programme development projects).

## 5.0 Introduction

The chapter presents a summary of the results obtained from the System development chapter. **Validation and verification of results is emphasized in this chapter.** The results for the Multi agent system developed in JADE will be outlined. The Barix program and web user interfaces are detailed as part of the results.

## 5.1 Output from the MAS Decision Making Process

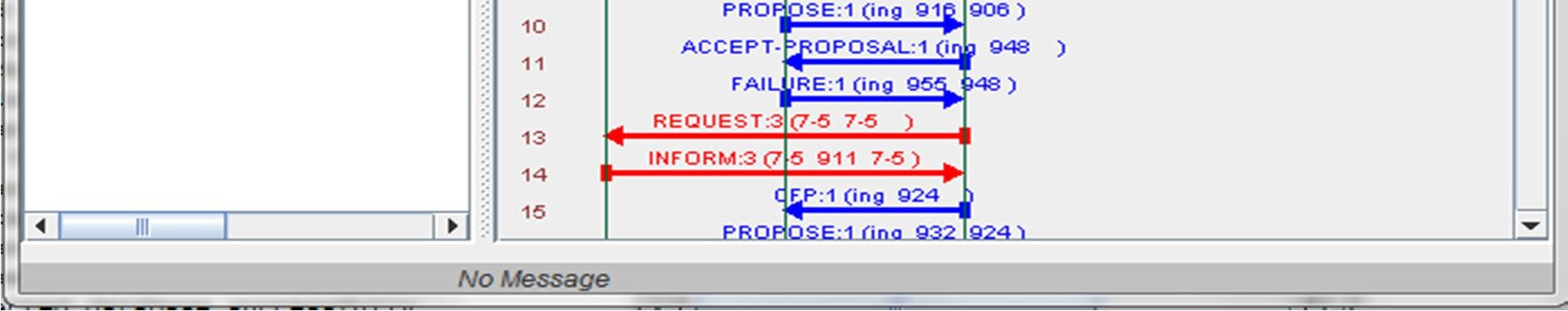
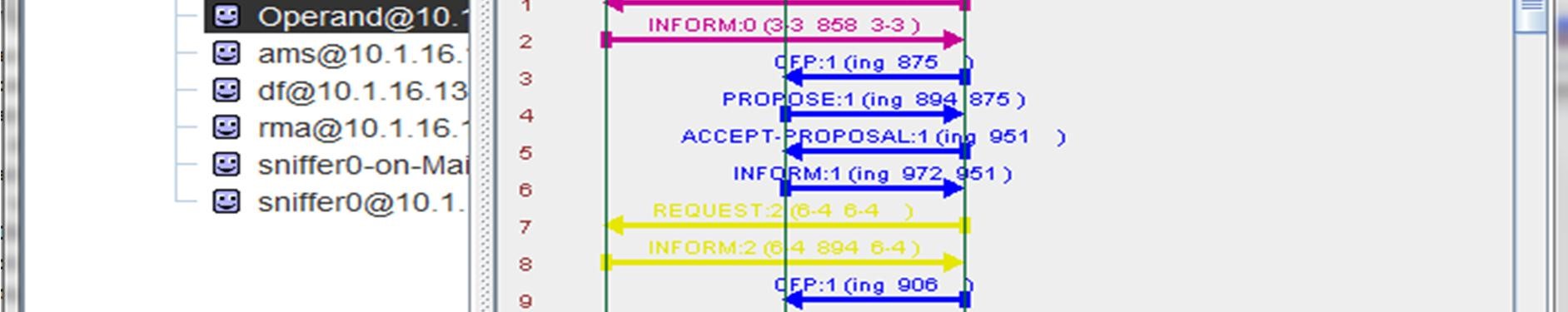
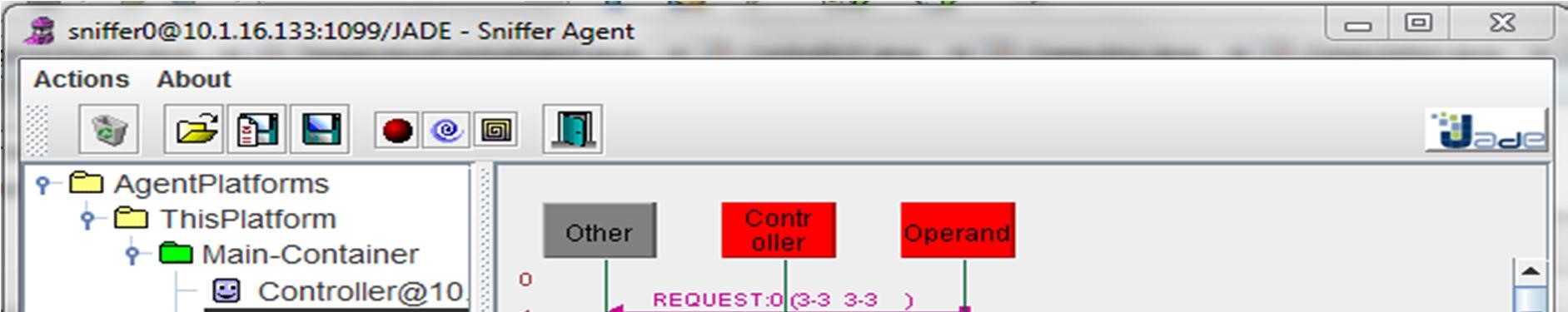
The outcome of the decision making process is detailed in the stack trace in Figure 5.1. The console platform details the input parameters for the decision making process, agent communication and the output decisions. The most important aspect of the stack trace is the detailed communications of roles played by the agents and the relaying of outputs of the decision making process in a cyclic process.



*Figure 5.1: Decisions and operations performed for scenario 1*

## 5.2 Intercepting Messages between Agents

A Sniffer agent was used to intercept agent messages between the Temperature Control agent (Controller) and the Operand agent (Operand) during the system temperature control. Messages in flight are displayed graphically using notation similar to UML sequence diagrams. Intercepting messages is useful for debugging the agent societies by observing how they exchange communicative or systematic messages in their communities. The Sniffer agent thus eavesdrops on the conversations in agent communities and the outcomes of this is displaced and summarized as shown below in Figure 5.1. The lines show the messages that are being exchanged between the agents.



*Figure 5.3: Sniffer agent results*

## 5.6 Summary

The mathematical model employed in the temperature control is developed from experiment 2‘s results and is applied in determining the actual mould temperature in the decision making agents. The decision making agents apply this stand point against the set mould parameters to aid in the temperature control system by setting up a predictive control structure. The Barionet100 is used in the system monitoring via the web user interface and the components used in the control. The application of the Barionet100 facilitates for the function of the multi agent system by providing the system inputs and as the receptor of all the commands sent via

the multi agent system. The heating elements are selected as well as the control valve for the cooling system.

# CHAPTER SIX – CONCLUSION AND RECOMMENDATIONS

(Gives the overall conclusion of the project and recommendations on further research to be done or areas that need attention but outside the scope of the project)

## 6.0 Introduction

The chapter outlines the conclusion and recommendations for the project. The recommendations are developed to focus on the maintenance and functionality issues related to the mould temperature control system. Future work on the project is also detailed in the chapter. The scope of future work highlights all the aspects that need to be considered, further researched on and developed in order to ensure a fully functional and efficient temperature control system.

## 6.1 Conclusion

The purpose of a conclusion is to tie together, or integrate the various issues, research, etc., covered in the body of the thesis, and to make comments upon the meaning of all of it. This includes noting any implications resulting from the discussion of the topic, as well as recommendations, forecasting future trends, and the need for further research. The conclusion chapter or section seeks to summarise the main points made in the introduction and review of the literature

* Review (very briefly) the research methods and/or design you employed.
* Repeat (in abbreviated form) your findings.
* Discuss the broader implications of those findings.
* Mention the limitations of your research (due to its scope or its weaknesses)
* Offer suggestions for future research related to yours.

## 6.2 Recommendations

The research that has been undertaken for this thesis has highlighted a number of topics on which further research would be beneficial. Recommendations act as the final summing up of your survey and can propose two things:

* Action to be taken based on your findings
* Future surveys in related topics

# REFERENCES

(Referencing styles to be used are the APA or the Harvard)

**Harvard Style of Referencing Examples**

BRITISH STANDARDS INSTITUTE. (1990). BS5605:1990. *Recommendations for citing and referencing published material*. Milton Keynes: BSI.

NEVILLE, C. (2010). *The Complete Guide to Referencing and Avoiding Plagiarism.2ND edition.* Open UP Study Skills. Maidenhead: Open University Press.

PEARS, R & SHIELDS, G. (2006) *Cite Them Right: The Essential Guide to Referencing and Plagiarism.* Newcastle-upon-Tyne: Northumbria University Press.

MORGAN, K. (2007). *Teaching Referencing Skills*. [Online] April 24th 2007. RefZone Discussion List. Available from: http://www.staffs.ac.uk/RefZoneList[Accessed: 2nd May 2008].

#### In-text example: (Morgan. 2007)

SADLER, P. (2003). *Strategic management*. [Online] Sterling: VA Kogan Page. Available from: http://www.netlibrary.com/Reader/. [Accessed: 6/5/2008]

**In-text example**: (Sadler, 2003)

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**Book with Single Author:**

Gore, A. (2006). *An inconvenient truth: The planetary emergency of global warming and what we can do about it.* Emmaus, PA: Rodale.

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Michaels, P. J., & Balling, R. C., Jr. (2000). *The satanic gases: Clearing the air about global*  *warming*. Washington, DC: Cato Institute. **In-text reference:** (Michaels & Balling, 2000)

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Galley. K. E. (Ed.). (2004). *Global climate change and wildlife in North America.* Bethesda, MD: Wildlife Society.

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New York State Department of Health. (2002). *After a sexual assault*. [Brochure]. Albany, NY:

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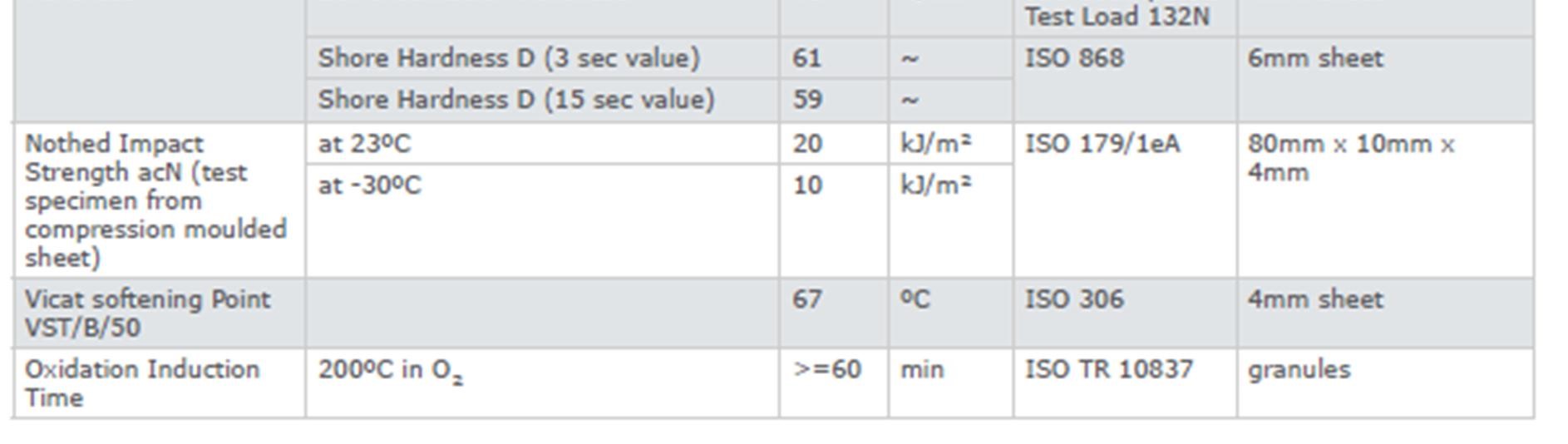
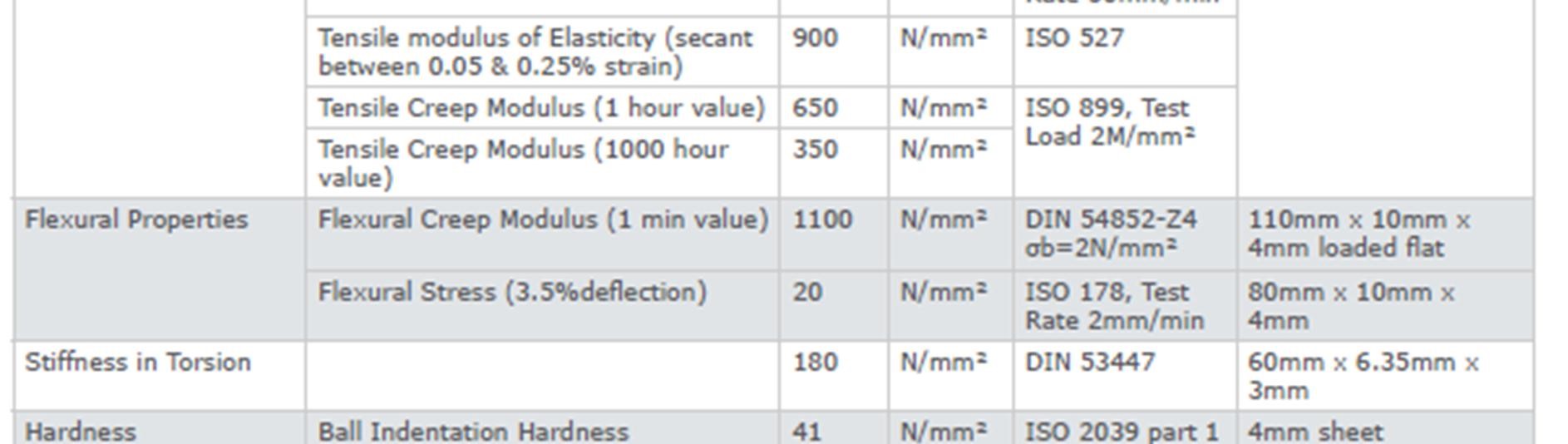
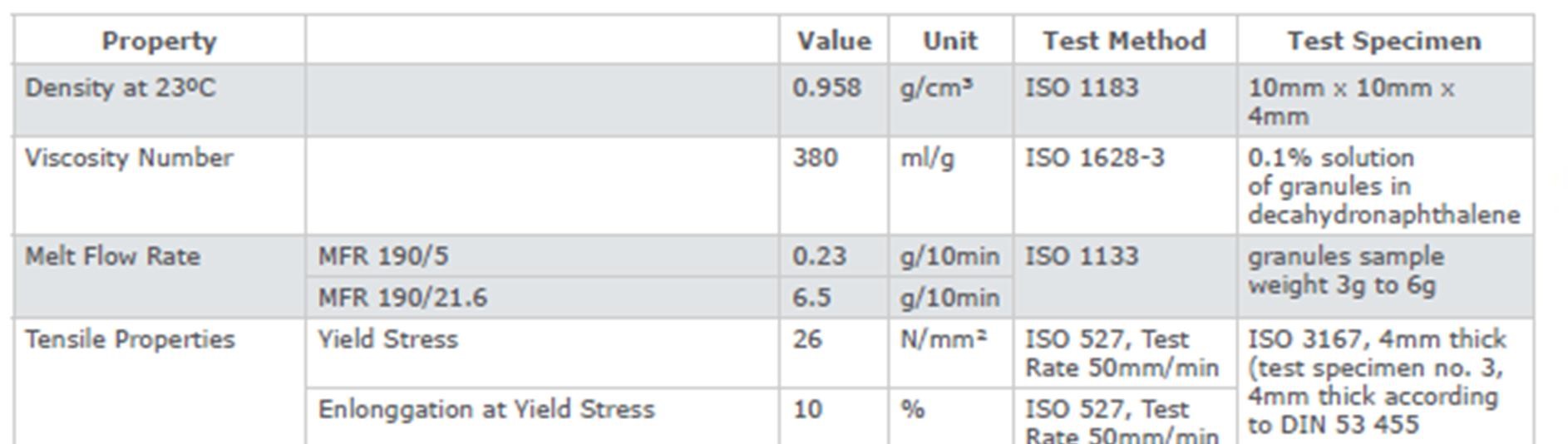
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Peattie, K., & Charter, M. (2003). Green marketing. *The marketing book*, *5*, 726-755.

# APPENDICES

Appendices allow the inclusion detailed information in the thesis that would be distracting in the main body of the thesis. Examples of items that maybe found in an appendix include mathematical proofs, lists of words, the questionnaire used in the research, a detailed description of an apparatus used in the research, etc.

**Appendix A1: Properties of High Density Polyethylene**



**Appendix A2: Materials selection criteria heating elements**

