1. INTRODUCTION

1.1. SCOPE OF THE WORK:

Multi-stage refrigeration systems are an area of growing industrial importance in large plants. These systems are known to be large power users and represent significant capital investment. Despite the current drop in oil prices, energy conservation is becoming increasingly important mainly from an environmental perspective, thus it has become necessary to design these systems for optimal performance, and this should take the control systems into consideration at an early stage in the design. This led to a new trend in industry where the equipment design and control systems designs are performed simultaneously in what is referred to as "plant wide control" (Dimian *et al*, 1997; Lausch *et al.*, 1998).

With the rapid development of computer technology, and the availability of more powerful computers, modelling has enjoyed accelerating growth as more accurate, though more complicated, models have become increasingly feasible. This requires powerful software, which enable the engineers to achieve full integration between the equipment and control design throughout all stages, thus helping to avoid some of the problems that used to be discovered later.

The work presented in this thesis is part of this new trend. This project aims to develop an approach to the dynamic modelling and simulation of a two-stage side-load refrigeration cycle with a single component working fluid, and to develop better control strategies rather than conventional ones for its effective operation.

To get a better understanding of how the system works, it is also intended to investigate and identify the interaction in this process, and assess its effect on the control strategy selected.

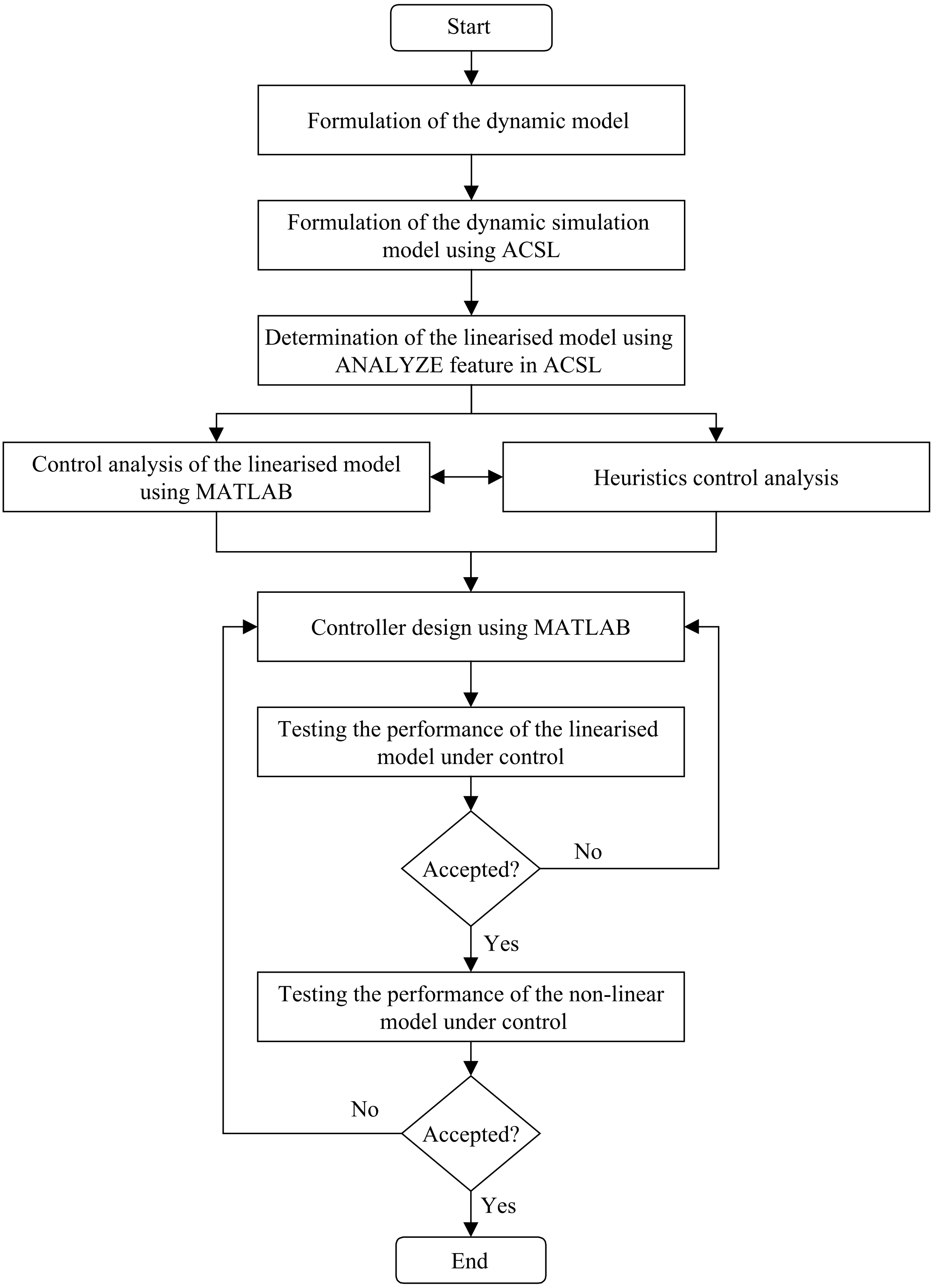

Figure 1.1: Control system design methodology

The methodology used in this project is fairly standard. As an example, Figure 1.1 summarises the methodology for the control system design, which comprises the main part of the work. It starts by formulating a dynamic model for the process, which is then used to develop a highly versatile ACSL simulation model. This model is used then to evaluate several control strategies in an attempt to improve the control performance of the process as a whole, and to identify any modifications needed at an early stage that will help avoid potential, and sometimes very expensive, control problems.

1.2. REFRIGERATION – GENERAL INTRODUCTION:

Refrigeration is a commonly used industrial process. In general, it is defined as the branch of science that deals with the process of reducing and maintaining the temperature of a space or material below its surroundings (Dossat, 1997). Refrigeration involves a range of subjects such as thermodynamics, heat transfer, hydraulics, mechanics, electrical technology and aerodynamics, and is applied extensively to food science.

In the last 100 years, refrigeration applications have become an integral part of daily life. Its applications not only include the obvious examples of household refrigerators and freezers, modern food processing, storage and transportation and air-conditioning processes only, but also industrial processes. In fact, the industrial applications of refrigeration are larger than the obvious commercial ones. Examples include refrigeration plants to remove the heat of chemical reactions, to liquefy process gases, for gas separation by distillation and condensation. Evans (1979) presented an overview of the different industrial refrigeration processes.

The design of the refrigeration system depends heavily on the working fluid used. Koelet (1991) summarises the characteristics of all common used refrigerants. Although some industries use their own products as refrigerants (e.g. ammonia plants), chlorofluorocarbons (CFCs) were used for years as the prime refrigerants in industrial processes. However, the role they play in causing ozone depletion resulted in an agreement signed to reduce production of ozone-depleting chemicals by 35% by 1999 in Montreal in 1987 and known as The Montreal Protocol. This was reviewed in 1992 and 11 more chemicals were added to the original 8 whose production should be reduced (Upshall, 1994). The growing environmental awareness, and the public concern regarding problems such as ozone depletion and the green house effect [(1)], lead to new researches into refrigeration processes. The researches went in two directions: to look for substitutes for the CFCs or to improve the performance of the refrigeration cycles to increase their efficiencies and decrease the energy consumption.

Typical refrigeration systems consist of four main stages:

- Evaporation
- Compression
- Condensation
- Expansion

Figure 1.2 shows a schematic diagram of a simple refrigeration cycle. The aim of the cycle is to cool the process stream. The stream entering the evaporator at temperature TPi is cooled to the temperature TPo by losing heat to the liquid refrigerant. The refrigerant is vaporised at constant temperature and pressure. The saturated vapour is drawn from the evaporator by the compressor. Vapour temperature and pressure both increase during compression, and the vapour is discharged in a superheated state to the condenser. In the condenser, it reduces heat to the cooling water or air, as its temperature is reduced to saturation and then condensed to form a saturated liquid. The condensate is collected in the receiver, from which the liquid flows, to complete the cycle, into the evaporator through an expansion device, often a control valve, where the pressure of the liquid is reduced to the evaporator pressure, and there is a corresponding drop in temperature. Part of the liquid flashes to vapour as a consequence of the pressure reduction.

The use of multi-stage refrigeration systems has increased significantly (McCarthy and Hopkins, 1971; Mehra, 1982; Gas Process Suppliers Association GPSA, 1994; Goldfarb and Oldham, 1996). Although these systems are large power consumers, it is a well known fact that they consume less energy by arranging to absorb heat by evaporating refrigerant at several pressure levels. This reduces running costs and leads

[(1)] 73% of the UK population think these are seriously dangerous (Burgess, 1993) to financial savings.

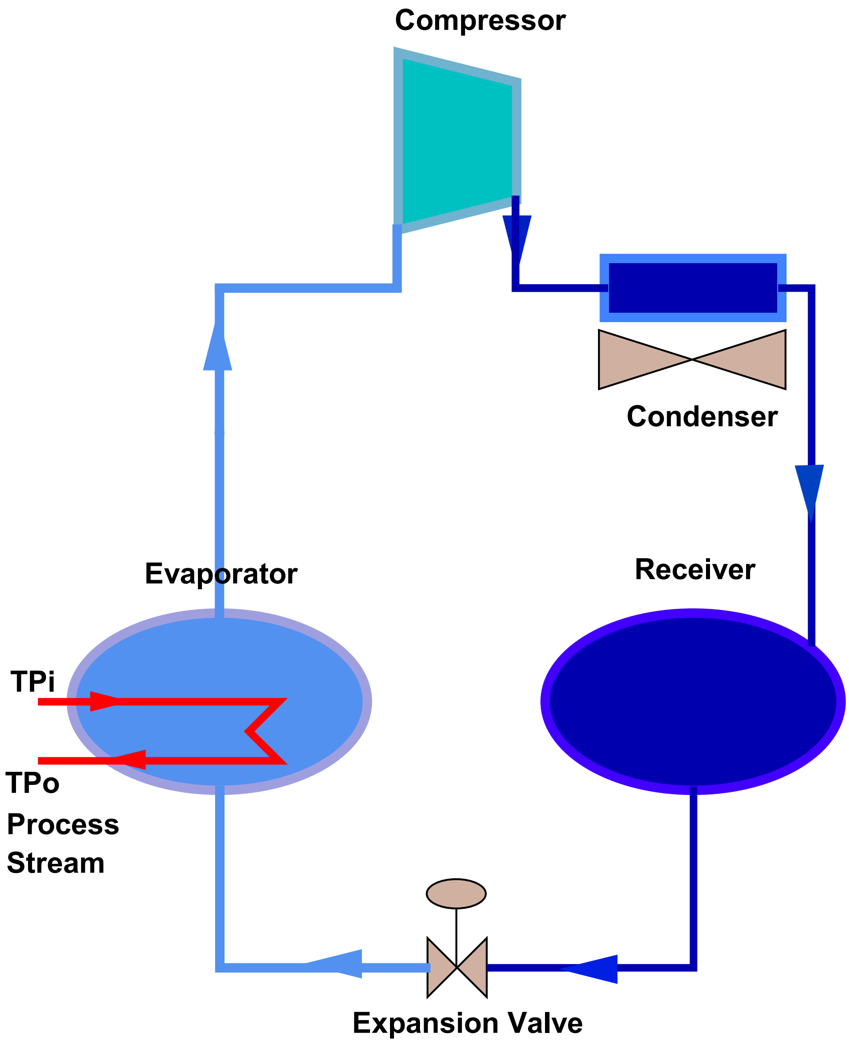

Figure 1.2: General refrigeration cycle

1.3. THESIS STRUCTURE:

This thesis consists of eight chapters including this one. Chapter 2 presents a literature review relating to the work done previously in control of multivariable processes and dynamic simulation of refrigeration systems.

Chapter 3 contains a full description of the dynamic model of a two-stage refrigeration system, and Chapter 4 presents the ACSL simulation model implemented and illustrates its validity.

The performance of this refrigeration system is analysed in Chapter 5, where three major control approaches are investigated. The main objective of the control strategy is identified as controlling the process outlet temperature, and the performance of each scheme is evaluated based upon its integral square error.

The control schemes are further investigated using several modern control analysis measures in Chapter 6. These measures were selected from literature to examine controllability, resiliency, interaction and pairing selection. A comparison between the performance obtained and the measures recommendations is included alongside a critical discussion. This also allows a critical evaluation of the techniques concerned and leads to conclusions on their applicability to refrigeration systems.

Chapter 7 presents an investigation of interaction involving development and application of an approach based on graph theory. A new interaction measure, the Input /Output Interaction Array IOIA is proposed as a useful general method in identifying the occurrence of interaction in control systems.

The overall conclusions of the work are summarised in Chapter 8.