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ABSTRACT

Sterilization in palm oil milling is the most important unit process because its initial and crucial influence on oil palm bunch fruitlets will determine the efficiency and effectiveness of the downstream milling process and even to the refining process in producing high grade palm oil. As an example, improper processing leading to high free fatty acids content will increase bleaching and deodorization cost in refining. As a consequence, a breakthrough in continuous sterilization will improve steam stability and efficiency of the mill and reduce labor in the sterilization operation among other process and cost benefits. In an on-going research contract with Kumpulan Guthrie Berhad (K.G.B.), a continuous sterilizer prototype fitted with a multiple fluids curtain attachment was built in the C.L.E.A.R laboratory. This is to study the viability of various gases and fluid injected in a jet curtain to retain sterilizing steam within the continuous sterilizer yet allow FFB to exit. Air, hot water and varying steam pressures were tested. The design is to exploit the thermodynamics of thermal and pressure equilibrium of the fluids to act as a counter-force to impede and retain the pressure and heat content of the escaping steam.The air curtain concept is extensively used in pollution and aeronautics to blend polluted emissions with clean air to lower black smoke and to reduce heat signature of aircraft exhaust. The prototype was rigged to an extensive temperature, pressure and flow rate measurement array to ascertain the velocity, temperature and pressure profiles of the steam and fluid. Hot water and compressed air were found to be the good insulators and retainers of the escaping steam based on the profiles obtained. Both limits the steam from escaping as well as delay premature steam condensation causing pressure reduction in the sterilizer. Apart from the temperature and pressure of the jet curtain, its efficiency also lies with the type of nozzles, arrangement of curtain jet and gap, all of which was investigated.

This process is greatly enhanced when the FFB is crushed and pre-treated which has been the on-going K.G.B. project with C.L.E.A.R. since 1996.

ABSTRAK

Pensterilan di dalam industri pengilangan kelapa sawit adalah merupakan satu proses terpenting kerana permulaan proses pensterilan dan pengaruh sesuatu gangguan terhadap buah kelapa sawit akan menentukan kecekapan dan keberkesanan di dalam proses pengilangan yang selanjutnya, malahan juga terhadap proses penyaringan dalam menghasilkan minyak kelapa sawit yang berkualiti tinggi. Sebagai contoh, pemprosesan yang tidak teratur akan menyebabkan bertambahnya kandungan asid lemak bebas dan meningkatkan kos pelunturan dan penyahbauan di loji penyaringan. Oleh yang demikian, suatu pengubahsuaian di dalam operasi pensterilan telah dikaji untuk mempertingkatkan kestabilan stim dan kecekapan proses pengilangan itu sendiri, dan seterusnya mengurangkan tenaga kerja dalam operasi pensterilan. Dalam usahasama penyelidikan bersama Kumpulan Guthrie Berhad (KGB), sebuah prototaip pensteril berterusan berskala makmal yang dilengkapi dengan lelangsir pelbagai bendalir telah direkabentuk di Makmal C.L.E.A.R. Ini bertujuan untuk mengkaji kebolehan pelbagai gas dan cecair yang disuntik ke jet lelangsir untuk memantapkan stim yang mensteril buah kelapa sawit segar di dalam pensterilan berterusan. Udara, air panas dan pelbagai tekanan stim telah diuji. Rekabentuk pensteril itu adalah untuk mengeksploitasi termodinamik bagi keseimbangan suhu dan tekanan bendalir-bendalir tersebut untuk bertindak sebagai *counter-force* untuk melengahkan dan memantapkan tekanan dan kandungan haba dalam stim yang terbebas. Konsep lelangsir udara digunakan secara meluas dalam pencemaran udara dan *aeronautics* untuk mengadunkan gas-gas yang tercemar daripada ekzos kapal terbang dengan udara bersih untuk merendahkan pengeluaran asap hitam dan mengurangkan kepanasan enjin kapal terbang. Prototaip tersebut dipadankan dengan kelengkapan pengukuran lanjutan suhu, tekanan dan kadar aliran untuk memperbetulkan profil-

profil halaju, suhu dan tekanan pada stim dan bendalir lain. Air panas dan udara termampat telah didapati berfungsi sebagai penebat dan pemantap yang baik bagi stim yang terbebas keluar, berdasarkan kepada profil-profil yang diperolehi. Kedua-duanya mengehadkan stim daripada terbebas keluar, di samping melengahkan pengkondensasian stim pra-matang, yang mengurangkan tekanan dalam pensteril. Di samping suhu dan tekanan jet lelangsir, kecekapan prototaip tersebut juga bersandarkan kepada jenis nozel, penyusunan ruangan dan jet lelangsir, yang kesemuanya telah ditentusahkan. Proses ini telah mempertingkatkan prestasi pensterilan buah kelapa sawit secara besar-besaran dan ia telah dijalankan secara usahasama projek K.G.B. dengan C.L.E.A.R. sejak 1996.

CHAPTER I

INTRODUCTION

1.8 Research Background

The primary goal is to realise the Dream Mill. At present, a research program is working on the projects mentioned below that have been identified as key elements of the Dream Mill to be develop into products as soon as possible.

i) A Continuous sterilizer to undertake 1 bar, 100 C continuous steam sterilization of pretreated fresh fruit bunches.

ii) An On-line, Real-time Oil Content Biosensor to measure oil content electronically during processing.

iii) Recovery of Red oil from Palm Pressed Fibre to increase EOR.

iv) An Internet-based system for training and collaborative problem solving between mills to solve problems collectively.

v) The design, model and integration of the new Dream Mill Process Flow sheet.

Below is the recent progress of the CLEAR Research Team. The implication of the each research product is cited in Table 1.1. In the following table, Table 1.2, showed

how the synergy of computation has enable the prototypes to be fabricated faster, accurately and smaller.

Characteristics of the prototype from experiments was computed to simulate various alternatives e.g. change of construction material, and to predict their performance, size, utilities requirement and layout virtually before a final decision is made to manufacture the product.

i) A Mathematical model, design and operating condition of the FFB pretreatment plant and a Mathematical model, design, operating conditions and a prototype of a continuous sterilizer.

ii) A new technique and sensor for measuring sterilization performance based on heat capacity.

iii) Mathematical model, design and a prototype of a biosensor to electronically detect and measure oil, water and fatty acids composition in palm fruitlets.

iv) A novel azeotropic extraction technique which can extract carotenoid rich oil from PPF and also remove fatty acids from the oil.

v) An Internet based knowledge database program to collect know-how remotely and undertake long distance training.

1.9 Scope Of Work

First and foremost, the Research Progress Report covers the progress, status and findings of the mutually agreed research program consisting of the research projects identified above. On the whole, the findings are technically very promising but it will require, on CLEAR side, thorough preparation to illustrate the principles involved and detailed explanation of the procedures, risks and rewards of the processes.

The mill manager's suggestions were to assess our findings and improve it. Accordingly, the computed and experimental findings on pretreatment, continuous sterilization, biosensor and the Internet Know-ledge database were benchmarked with the operation data at these mills.

1.10 Benchmarking

These are the current performance parameters in pre-treatment and continuous sterilizations that are being used to evaluate the success and progress of the research.

i) USB and its relationships with OER.
ii) Degree of sterilization by new measurements using heat capacity and biosensor capacitance.
iii) Cycle time per tonne FFB.
iv) Steam consumption per tonne FFB.
v) FFA reduction during processing.
vi) Number of equipment.
vii) Number of laborers.
viii) Cost of capital and operating (inclusive operations of laborers) per tonne FFB processed.
x) Amount of utilities used – water, steam, power, labour per tonne FFB.
ix) Pre-treatment requirements and cost – Solid disposal, water recovery and steam conservation per tonne FFB.

1.11 Background

A modern mill must resolve to tackle these critical and pressing problems in the industry :

i) Automation - to save labour, resources and energy, a continuous sterilizer has been the focus of research since it perceived to solve these problems.

ii) Increase OER – to increase recovery of residual oil in the fibres – double pressing has been perceived to address this but is still undecided.

iii) Downstream processing – refining of the CPO costs has been increasing – the setup of refinery at mills has been tried at East Malaysia but as yet undecided.

The hypothesis is whether the modern mill should adopt an evolutionary or revolutionary strategy in meeting the objective.

This research thus, far has been able to answer these questions and give assessment of the changes to be made towards the realization of modern mill. It has concluded that changes must be revolutionary not evolutionary, to reengineer current technologies. Change is inevitable in areas of automation, information technology, chemical processing, training and education to bring about the Dream Mill Concept. Consequently, these changes are not only in terms of machines and information but also in the human; education, knowledge and practice. Without which, the Dream Mill will forever remain a forlorn mirage. By far, the biggest challenge faced by KGB is KGB itself. KGB must transform itself in revolutionary terms. In fact, due to the multitude and inter-acting problems, a revolutionary altitude is necessary to ensure a ‘clean sheet’ perspective to the problems.

1.12 Fibre Life Cycle

This section explained the features of the life cycle of the fibre. Of course, at each stage of the life cycle, inputs are required and output-wastes are produced.

i) The common inputs throughout the whole cycles are steam, power, water and in certain processes; solvent and air which are both recoverable. Power and steam are both produced from the fibres at the end of the cycle. The FFB capacity of the process is proportional to the amount of power and steam produced by fibres. It can be supplemented by burning the empty fruit bunches and kernels.

ii) In contrast, there are a multitude of outputs – slurries, acidic water, oil water, CPO, red oil and finally the solvent. The first three are major pollutants but with the use of hot air, heated by steam, the water load of the pollutant can be reduced significantly by about 50%.

iii) The next 2 outputs are revenue products. The extraction of red oil would increase EOR by about 0.9% in weight and yield carotene of 3000 ppm, value at RM1, 000 per litre for crude carotene-rich crude palm oil.

iv) There is little or no stearin in the oil, which would cause premature crystallization. The FFA is slightly below normal, in this case about 1.0%, and can be eliminated by the water azeotropic decanter.

v) The solvent is recoverable by azeotropic distillation.

vi) Let us then look at the processes selected for each stage of the cycle. Currently, the washing and heating stages consumed a lot of water for washing and heating. As shown earlier (Progress report 1997), deploying dissolved Air Flotation (D.A.F) into washing can reduce 50% of the water load. Similarly, the exhaust steam heats the compressed air for the D.A.F. Input steam of the sterilizer can be used to heat up the water for the washer and heater. Admittedly, the degree of water pollution in FFB washer occurs is limited compared to the savings in water and steam. The extensive use of heated air would aid the utilization of excessive water and steam for heating. These will primarily lower steam: FFB

demand. Alternatively, the hot water can be produced from unused steam of the sterilizer and recycled condensates (which is dirty). This approach is worth investigating in the future since the kernel section used heated air successfully for drying.

vii) As for the solvent, it has not direct contact with the CPO. It is being used solely in the red oil extraction and helps to preserve its potency. Its recovery is also conducted at lower temperature due to the decanter and which would save energy and avoid high flash point hazard in the mill, like hexane.

1.12.1 Other Aspects In The Fibre Cycle

Apart from Chemara work on the utilization of EFB for furniture, the obvious use is to burn it for more energy. One should then be cautious of its effect and impact on air pollution. What benefits that may be financially derived from EFB is far from answered. Its application as a fertilizer is a long-term strategy should be considered as cost savings in the fertilizer industry not only for oil palm but also other food crops perhaps.

There is a distinct advantage in viewing the workings of the mill, not as a linear production line of materials, but as a cycle of materials leading to a cycle of events. To this end, the ISO14000 analysis of a mill since it is also based on a cycle-analysis of the life cycle studies made easier. In fact, other cycles are; the liquid cycle consisting, oil, water, fatty acid and insoluble matters. The vapor cycle consists of steam, hot water and condensate.

In hindsight, the value of the cycle perspective offered a number of benefits in the optimal utilization of resources by understanding the inputs, outputs and requirement. This is a new way of describing a process.

1.13 Pretreatment

Undoubtedly, the bulk of water used for Pretreatment and the energy consumed by the long conveyors as well as the enormity of the pilot plant are of great concern. One lesson of the Bukit Kerayong pilot plant is that wastage of water, energy and size will make the Dream Mill infeasible to build and unwieldy to operate.

i) After comparing Ulu Remis and Bukit Kerayong, the real problem lies not with the heavier than water solids but the suspended solids contaminating and accumulating in the Jacuzzi. The addition of the two clarifiers with an additional 20,000 litres of water to resolve the problem of solid wastes is unclear at the moment. Instead, it is recommended that high pressure water spraying and high pressure air bubbling in the Jacuzzi will reduce water consumption, clean away the debris faster and concentrate the waste into a smaller volume. By using sprays, the suspended solids and heavier than water solids can be lumped together and disposed continuously as a slurry. Excessive water only deteriorates the problem by providing a media for solids to be suspended and it is more difficult to remove suspended solids than flowing slurry.

ii) One inquiry is on the design of the 2 clarifiers which required a total 20,000 litres of water. Are the particle size and weight distributions of the suspension available so that the settling time and depth of the clarifier be determined? .

iii) Alternatively, hot compressed air can be also be used in the washer hence lowering the steam required to provide sterilization.

iv) Recycle the hot condensate and hot unused steam from the sterilizer to the water to heat up the water for the washer heater. It is reiterated that the use of heated air to supplement hot water is economical and necessary to reduce the pollutant load.

1.14 The Continuous Sterilizer And Hot Water Heater Integration

Our computation and experiment coupled with the previous Bukit Kerayong static continuous sterilizer result have shown that continuous sterilization is possible.

i) The recent Downsizing of the Bukit Kerayong plant is in line with the recommendation to bind together the heater and the continuous sterilizer as a single unit.

ii) It must be conducted at least 1.5 bar and 120 ^{c} to achieve at least 68 minutes sterilization time and still maintain the rate of 60 tonnes FFB per hour. The pretreated fresh fruit bunch must be preferably only one or two layers thick, well crushed and split. Thus, the size of the sterilizer must be minimized l so that the steam impact immediately with the crushed bunches and the resulting condensate can be evacuated as rapidly as possible to prevent build-up.

iii) On this matter, an experiment to simulate a pilot plant scale operation of the continuous heater and sterilizer combination by re-using the existing pretreatment plant in Bukit Kerayong is being proposed.

iv) The critical question is the mode of applying steam to the pretreated bunches, whether by high pressure steam spraying from above or by steam induced fluidization from the bottom, is the best method to sterilize the pretreated fruit bunch?.

1.8 The Computation of Dream Mill

Further on, the computation element of the research was able to model, design and integrate the pretreatment, continuous sterilizer, biosensor and Red oil processes into a single integrated plant. Therefore, the sizes, capacity, utilities requirement and preliminary costing of the major units under our scope of work were calculated.

i) The estimated equipment cost (clean without piping and pumping) is estimated at RM3.76 x 10^6 (total of pre-treatment, steam supply, continuous sterilizer, bio-sensor and Red oil process). The percentage of actual current cost is about a 33.3% of total cost of a new mill at RM 12 x 10^6.

ii) Savings that can be accrued from dream mill research products:

iii) Eliminate workers at the sterilization stations.

iv) Eliminate 4 sterilizer to 2 sterilizer (50% reduced)

v) Eliminate steam fluctuations; reduced 20% steam losses and 20% more steam available.

vi) Reduce utilities; water, steam and power.

vii) Create a new product - Red oil at RM1000 per tonne basis of economic calculation.

viii) Consistent quality control by using Biosensors and Heat Capacity. So that, the OER can be determined continuously.

1.9 Problems and Delay

An unstable economy caused much delay in procurement. Next, the precise and complex design of our equipment troubled our local vendors and had to be advised closely to achieve the precision required. Finally being aware of the current economic stress, there was a compromise on time to ensure that the existing grant would be sufficient to finish the prototypes.

In the former, since the currency control in September 1998, the Customs are strict on imported items especially the precision flow rate steam generator since there is no tax for research instrument. We have overcome this and the delivery and installation of the steam generator is due in mid-November. Understand, this has prevented the link – up with the spray sterilizer and biosensor prototypes.

In the latter case, the biosensor is very sensitive instrument able of measuring very small capacitance of 10^{-6} to 10^{-9} faraday and the entire unit must be well insulated. Similarly, the nozzle procurement, design and installation of the spray sterilizer were another detailed and precise design. Extensive advice and guidance not only on the design and fabrication of the instrument but also on the quality of manuals were emphasized which consumed much time.

Table 1.1 : The Implications of each research product.

NO.	PRODUCT	IMPACT
1	Mathematical model, design and operating condition of the FFB pretreatment plant.	Simulate various process & operating conditions to minimise wastes and energy to optimize production.
2	Mathematical model, design, operating conditions and a prototype of a continuous sterilizer.	Simulate various process & operating conditions to achieve sterilization continuously at 1.5 bar and less than 90 minutes.
3	A new technique and sensor for measuring sterilization performance based on heat capacity.	An accurate and real-time measurement of sterilization based on measurable components, operating variables and energy consumed.
4	Mathematical model, design and a prototype of a biosensor to electronically detect and measure oil, water and fatty acids composition in palm fruitlets.	Real-time, in-situ and portable sensor to measure sterilization as well as oil, water and fatty acids content in fruitlets and FFB.
5	A novel azeotropic extraction technique which can extract carotenoid rich oil from PPF and also remove fatty acids from the oil.	Use of water-based ethanol solvent to extract and purify oil safer, more efficiently and more cheaply than using hazardous and flammable pure ethanol increasing safety and handling.
6	An Internet based knowledge database program to collect know-how remotely and undertake long distance training.	Reduce time and cost in training, problem-solving and store in-house know-how.

Table 1.2: The Synergy of Computation

NO.	PRODUCT	TASKS	OUTCOME
1	Mathematical model, design and operating condition of the FFB pretreatment plant and continuous sterilizer.	Simulate various process & operating conditions to minimise wastes and energy to optimise production. Simulate various process & operating conditions to achieve sterilization continuously at 1.5 bar and less than 90 minutes.	Evaluate the design, size, utilities consumptions, material flow and cost of the equipment as well as evaluate its economics, manufacturability and impact on existing mill.
2	Mathematical model, design, operating conditions of steam, water and power systems to supply, recover and dispose materials.	Simulate various process & operating conditions to minimise wastes and energy to optimise production.	Evaluate the design, size, utilities consumptions, material flow and cost of the equipment as well as evaluate its economics and impact on existing mill.
5	Mathematical model, design, operating conditions and a prototype of a azeotropic extraction technique which can extract carotenoid rich oil from PPF and also remove fatty acids from the oil.	Simulate various process & operating conditions to minimise wastes and energy to optimise production. Impact of water-based ethanol solvent on safety and handling.	Evaluate the design, size, utilities consumptions, material flow and cost of the equipment as well as evaluate its economics, manufacturability and impact on existing mill.

CHAPTER II

LITERATURE REVIEW ON CONTINUOUS STERILIZER

2.3 Introduction

Sterilization of the FFB essentially based on the principle of steam penetration into a fruitlet and bunch. Sterilization consist of the partial or total destruction of viable microorganisms which otherwise will cause deterioration of food quality and/or food poisoning (S.H.Lin, 1979). According from Mongona report (1955), sterilization prevents further rise in free fatty acids due to enzymatic lipolysis and condition the bunch and facilitating subsequent processing. The usual method of sterilization is a batch process which has to supply the feed needed to maintain the subsequent extraction processes in continuous operation. Any interruption in the supply of sterilised fruit results in a disruption of downstream processing which leads not only to loss of throughput but also to loss of product resulting from a lower efficiency of operation. As a result, a concept of continuous sterilization is introduced to reduce labour, maintenance, save time and enhance the quality of palm oil.

The aim of the study on the continuous sterilizer is to evaluate the performance and the design of the unit. This information is to predict the size of the sterilizer and capacity to deliver the energy to attain USB = 0 %.

A field survey of the prototype static model of the continuous sterilizer was conducted to evaluate the performance and design of the unit.

2.4 Theory And Design Of Continuous Sterilizer

This research is to determine the viability of various gases and fluid injected in a jet curtain to retain sterilizing steam within the continuous sterilizer yet allow Fresh Fruit Bunch (FFB) to exit. Air, hot water and varying steam pressures were tested. The design is to exploit the thermodynamics of thermal and pressure equilibrium of the fluids to act as a counter-force to impede and retain the pressure and heat content of the escaping steam.

A sterilizer with a jet curtain attachment was built in the Centre of Lipids Engineering and Applied Research (CLEAR) laboratory (Figure 2.1 and Figure 2.2). This comprises of the boiler, an air compressor, a sterilizer unit with a detachable an air curtain attachment and the necessary data acquisition equipment to measure the temperature and pressure profiles. This is to study the viability of a fluid jet curtain to retain steam within the continuous sterilizer during sterilization process.

Simultaneously, the unit also measures, by electrical capacitance and heat capacity methods, the degree of sterilization of fresh fruitlets. These are new methods of analytical measurement of sterilization to improve the accuracy and reliability of the results and to complement the Un Stripped Bunches (U.S.B.) parameter in use. These new combined measurement techniques of sterilization will be discussed briefly and will be published in full later.

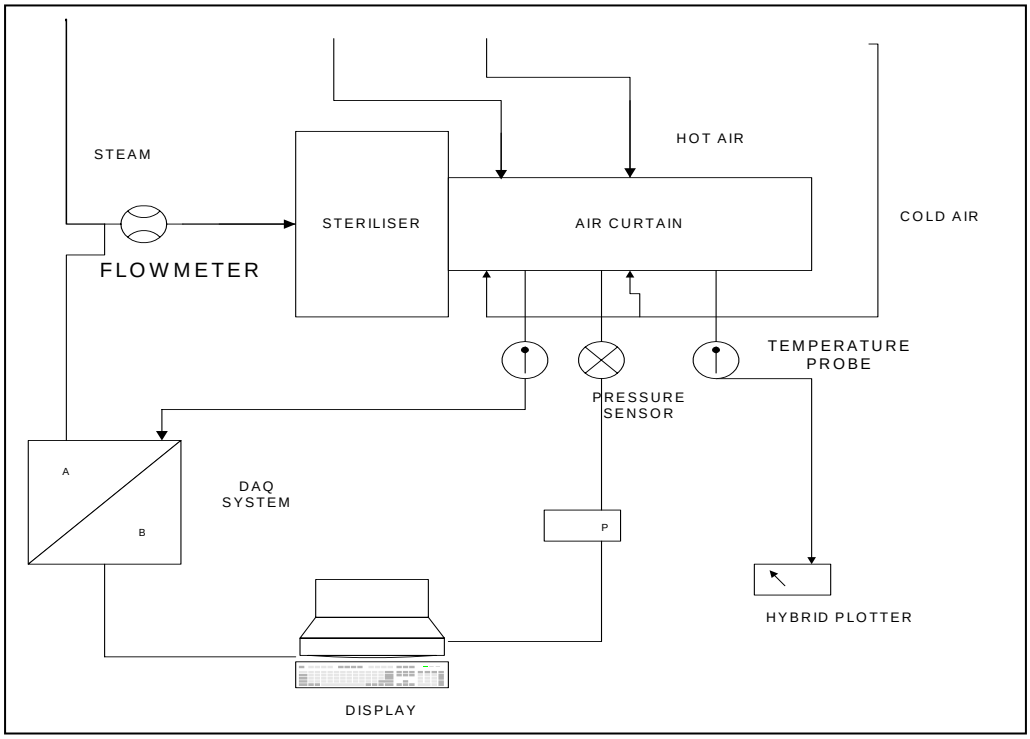

Figure 2.1 : Schematic Diagram of Sterilizer with an Air Curtain Attachment Set-Up

Figure 2.2: Profiler of the Sterilizer with an Air Curtain and Sensor Attachment Set-Up

2.3 Fluid Jet Curtain Rig

The aim of the rig was to determine whether hot fluids; air, water or steam with a higher pressure on the other side of the sterilizer could exert an equal pressure to contain the escaping sterilizer steam. The presence of the sterilized FFB as a physical restriction will improve the seal since it occupies a large physical space and reduce the area of steam escape to the outside. Thus, the presence of a large FFB and an opposing fluid with higher pressure would limit escape.

2.5 Palm Oil Milling Process

The main steps for milling process are:

2.5.1 Loading Sterilizer Cages

FFB arrival in the mills are transferred on to a ramp and tipped into a chute. Rail cages are loaded the chute and each 2 .5 tone loaded cages are pushed into horizontal cylindrical vessels.

2.4.2 Sterilizer

FFB cooked batch wisely using steam at 40-psi pressure for about 30-45 minutes. The condensate is drained after every sterilization cycle.

2.4.3 Bunch Stripping

The cages of sterilized fruit bunches are hoisted and emptied into the bunch stripper .The stripper consists of a horizontal rotating drums onto which each bunch is lifted and dropped several times to detach the fruitlets from the main stalk. The empty bunches are discarded.

2.4.8 Digester

Fruitlets are then conveyed to the digester, a vertical cylindrical steam Jacketed vessel. The inside is fitted with beater arms, which churn and mash up the fruitlets loosening the fibrous mesocarp from the nuts.

2.4.9 Screw Press

The mash fruit let is conveyed to the long screw press .The back pressure within the press is adjusted by means of a cone to obtain maximum oil expulsion with minimal breakage of the nuts.

2.4.10 Vibrating Screen

The screen usually has 20-40 meshes where the coarser particles are screened off and the liquor passed to the settling tank. Water is usually added to the oil at this stage. This helps better separation in the next stage of processing.

2.4.11 Settling Tank

Residence time is about two hours, the oil being of lower density, floats to the top and is skimmed off. A layer of sludge labeled as the underflow consisting of about 10 percent oil, 7 percent non-oil solids and 84 percent water remains at the bottom.

CHAPTER III

METHODOLOGY

3.1 Experimental Set-Up

The various conditions of the sterilizer is summarised in the flowchart of Figure 3.1 below. The closed sterilizer (Figure 3.2) was used as a control experiment and is comparable to the present batch sterilization used in the palm oil mill. For comparison, the pressure of the steam used in the sterilizer was maintained at 2.5 bars for and the jet flow rate was constant throughout the entire curtain and in all experiments.

The experiments were generally divided into two; the study with fruits (1/8 bunch) and without fruits. The study with fruits was to establish the degree of sterilization under various conditions. The study without fruits was to obtain both the temperature and pressure profiles under various conditions.

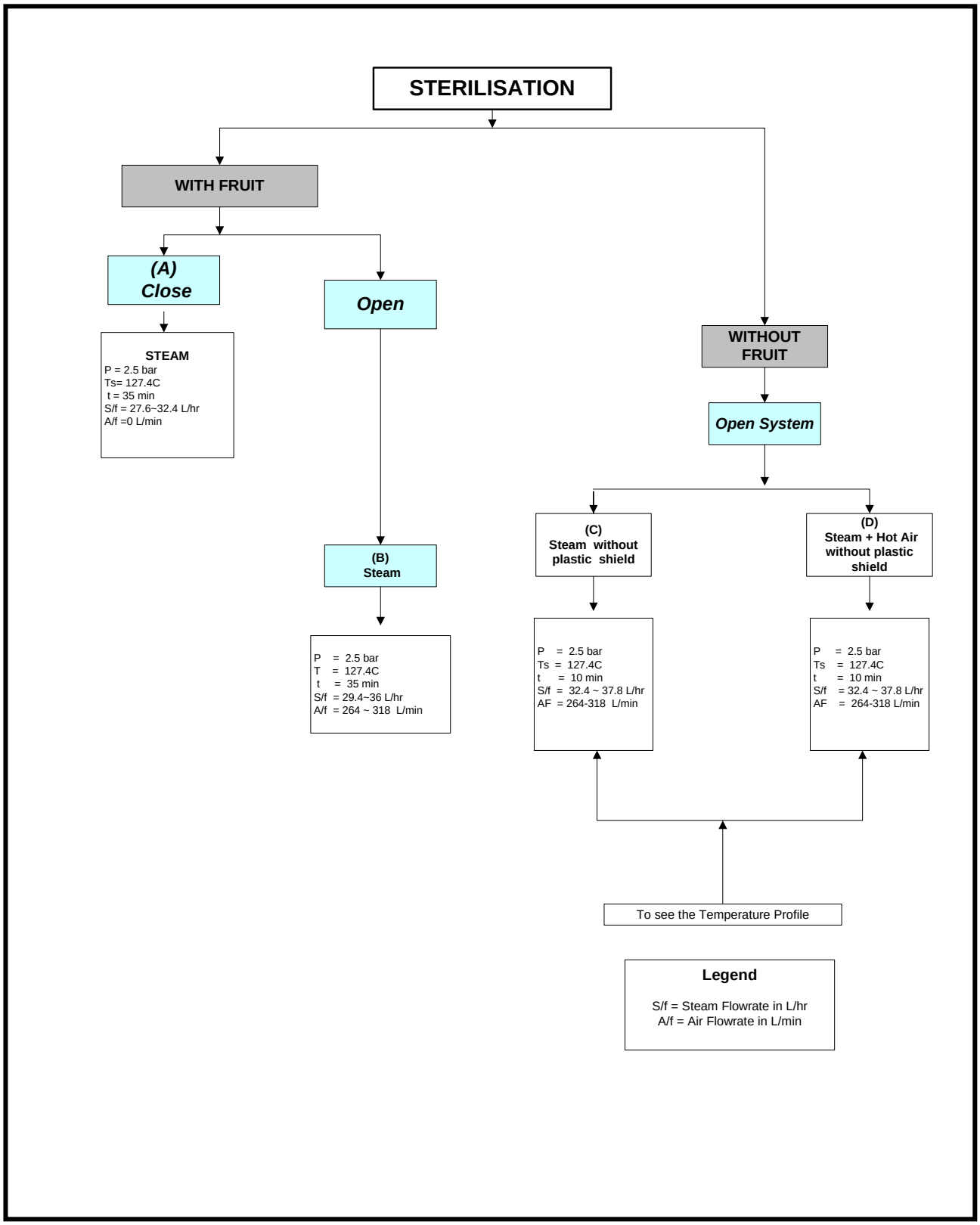

Figure 3.1: Flowchart of Research Methodology for Continuous Sterilizer

3.2 Experimental Procedure

Referring to Figure 3.1, the experimental procedures were as follows.

3.2.1 Steam Flow rate Measurement

The assumption made was that 10% losses of water/steam to the surrounding. The amount of water consumed was measured by noting the initial and final water levels in the water tank. The total volume of water consumed divided by the total experimental duration gives the steam flow rate.

3.2.2 Air Flow rate Measurement

The airflow rate was measured by noting the initial and final pressures the air in the compressor. The time for air release was also taken. The ideal gas law was used to estimate the airflow rate. Currently, a flow meter has taken over this function in the jet curtain.

3.2.3 Sterilization With Fruits.

3.2.3.1 Experiment A: Sterilization with Fruits for Close System.

Boiler and the sterilizer unit with the door were used. Fresh Fruit Bunch (FFB), were obtained from Bukit Kerayong mill and cut into 1/8 of a bunch. The DSC and capacitance reading of the fruit samples were taken. The bunch was placed in the close sterilizer system where the sterilizer door closed as shown as Figure 3.2. Steam was let into the chamber for 35 min.

Figure 3.2: Picture for the Close Sterilizer System

3.2.3.2 Experiment B: Sterilization with Fruits for Open System.

In experiment B the sample of fruit was put inside the sterilizer (Figure 3.3), the compressor was switch on and air was let into the jet curtain chamber (Figure 3.4) throughout the experimental duration. Finally, the Differential Scanning Calorimeter (DSC) and capacitance reading of the samples were taken (Figure 3.5).

Figure 3.3 : Sterilization with Fruit

Figure 3.4: Sterilization with Steam and Hot Air

3.2.3.3 Sterilization Without Fruits

The temperature and pressure profiles were obtained using K-type thermocouples and pressure sensor attached to the data acquisition equipments. The readings were taken for an experimental duration of 10 min at 2 minutes intervals. The probe locations are as shown in Figures 3.5 and Figure 3.6 where the probe location were Row A (Top), Row B (Middle) and Row C (Bottom).

The PROFILER was used to measure temperature and pressure profiles for experiments C and D as Illustrated in Figure 3.1.

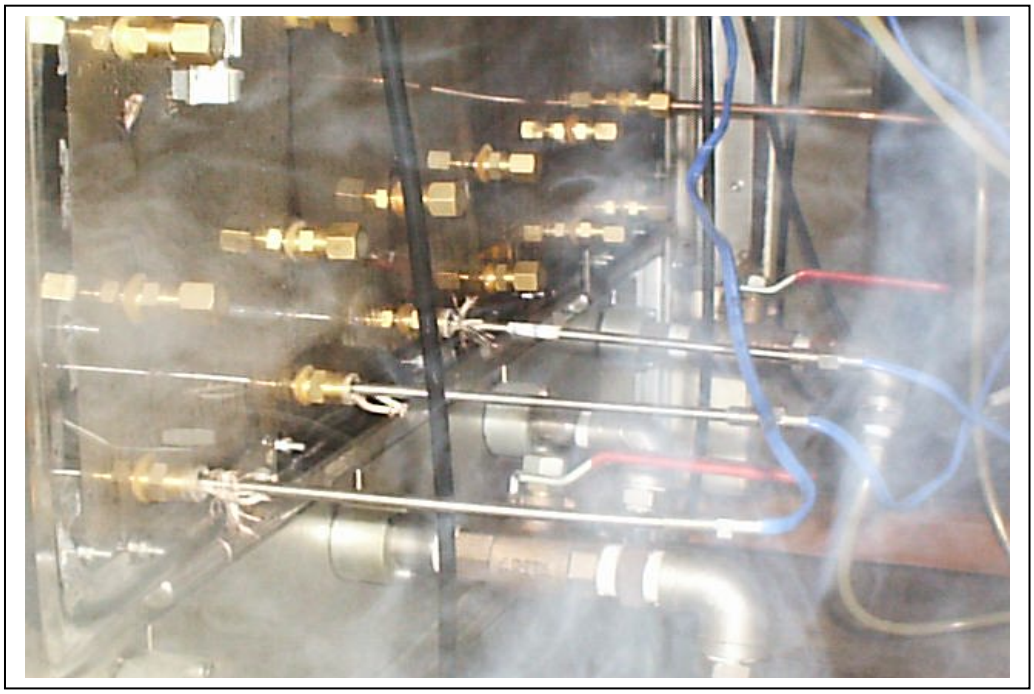

Figure 3.5: Thermocouple probe location at Ro

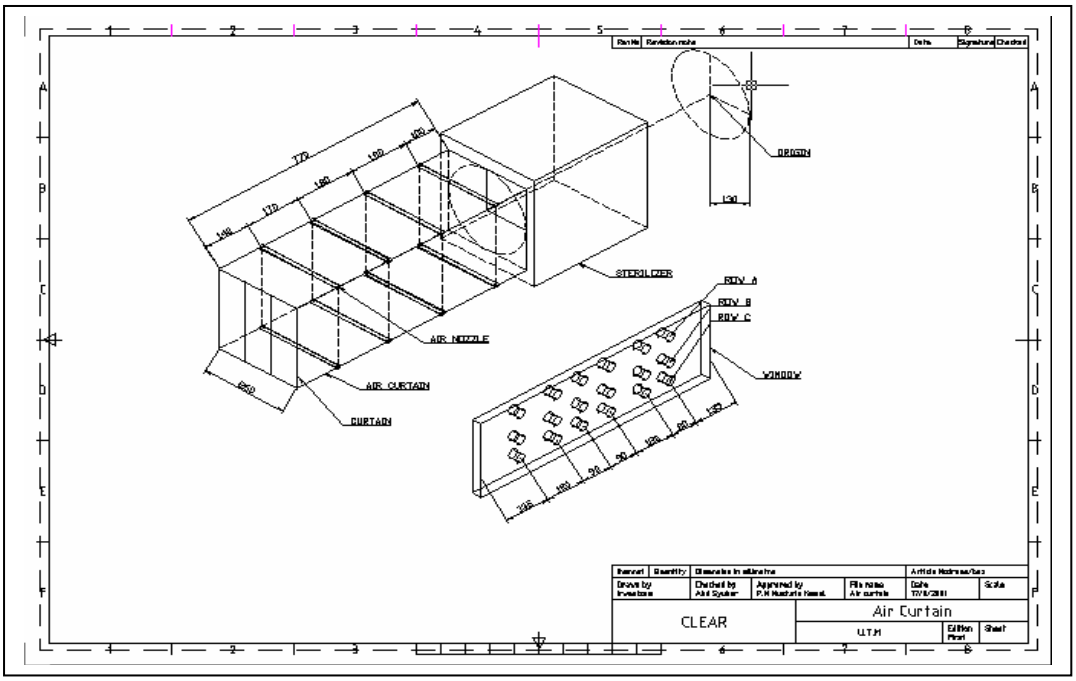

Figure 3.6: 3D View For Air Curtain and Probe Location

3.3.3.4 Experiment C: Sterilization without Fruits for Steam Only

Steam was let into the chamber for 15 minutes, for steady state condition and the compressor was not switch on.

3.3.3.5 Experiment D: Sterilization without Fruits for Steam and Hot Air

Steam was let into the chamber for 15 minutes for steady state condition and the compressor was switched on and air was let into the jet curtain chamber throughout the experimental duration.

3.2.6 Measurement of Degree of Sterilization

Three types of samples i.e. fresh, pretreated and sterilized fruits were studied. The readings for capacitance was obtained using the capacitance jig developed earlier as shown as Figure 10. Palm oil fruitless (10 - 20 g) as well as 1/8-bunch readings (1.5 - 2.8 kg) were taken using capacitance jig. The DSC (Figure 3.7) was also used to measure the various readings of the samples.

Figure 3.7 : Diffential Scanning Calorimetry (DSC)

3.3 Fundamental Hypothesis & Findings (Concept)

The modelling of the fruitlet heat penetration system in a continuous sterilizer was undertaken using a spreadsheet model. Spreadsheet modelling allows many parameters to be studied and its significance on the overall performance of heat penetration evaluated quickly and easily. Spreadsheet modelling is transparent (no black box preventing the user from changing the formulate underlying any calculation), inexpensive and the software is readily available and easy to run. Using spreadsheet modelling, one can answer quickly questions on the effect of selected variables on the process of heat penetration. Spreadsheet formulation can be viewed, understood and modified.

The modelling is developed from a two-dimensional, time-dependent, unsteady state, heat conduction by using finite-difference-explicit method. A fruitlet of oil palm is assumed as a slab which is divided equally into 30 square sub-regions by a network of mesh size $\Delta x = \Delta y = l = 0.003$ m and the time domain is divided into small time steps Δt. The two dimensional model was found to be more accurate since temperature distribution are presented in more detail compared to the one-dimensional model.

Physical properties of the fruitlet; k, thermal conductivity, α, thermal diffusivity and Cp, heat capacity are important to predict the residential time. Physical properties used in the modelling at initial stage were taken from literature study (Masitah et. al).

To test the validity of the properties used, an experiment was done to carry out to find the value of Cp of the fruitlet mesocarp. The Differential Scanning Calorimetry (DSC) equipment was used to study three samples consisting of fresh fruit, pre-treated fruit and sterilized fruit. From the literature, Dr. Masitah froze the sample at $4^{O}C$ but the from Mongana Report reported that freezing the oil palm fruitlet will lead to the formation of free fatty acid in the fruit where this will finally effect the experiment result, C_P. In this case, the experiment was being run immediately after the samples are collected to avoid the above problem. The results were used in the heat penetration model.

From the sensitivity analysis of the model, increasing of the value of k will lower the residential time taken to sterilize the fruit. The conclusion is that an increase of water content in fruitlet will increase k and consequently decrease the time residence. The results of sensitivity analysis were:

i) Heat Transfer Coefficient Vs Time

ii) Restriction Of Stability Vs Time

iii) Time Step Vs Time

iv) Final Temperature Vs Time

The beginning of sensitivity analysis was the running of the model with only one parameter changing at a time. The model outputs were analyzed to ascertain the extent to which changes in a parameter changed the outputs. The parameters were then ranked by the degree of output sensitivity to them. Finally alternative options and strategies were made to achieve good simulated outputs.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Pressure Cell Curtain Fluid Selection

4.1.1 High Pressure Steam

With high pressure steam as a curtain, a higher pressure steam front would develop in since the escaping sterilizing steam would combined with curtain steam to exert a higher force. As a consequence, this front would not retard steam escape but enhance it due to the additive nature of the steam to form a steam front.

4.1.2 Hot Water

With hot water, the sterilizing steam being of higher temperature would condense in the face of the hot water jet and a steam front is avoided. Instead, the sterilizer steam condenses and combined with the hot water jet as condensate.

A waterfront would develop instead; similar to rainfall front when hot humid air is confronted with cold dry air.

If the condensate is not exhausted immediately, a build up will occur and move in the direction of the feeding sterilizer steam. This operation requires good condensate outflow and better insulation so that the hot water temperature is kept at maximum, if possible approaching 100°C. The smaller the temperatures difference between the hot water and steam the slower the condensation rate.

4.1.3 Compressed Hot Air

High-pressure compressed air due to the density difference will pushed back the steam. At a higher pressure and temperature, it would retard steam escape and steam condensation since the temperature will not allow it to condense.

4.1.2 Calculation of Sterilising Steam to Hot Air Ratio In Jet Curtain.

4.1.2.1 Steam Flow rate

The steam flow rates for the experiments when the boiler was maintained at 2.5 bars were as tabulated in Table 4.1. From the steam flow rate calculation; the average steam flow rate was 0.56 L/min.

Table 4.1: Steam Flow rates Calculated for Open System for Experimental Runs of 35 Minutes

No.	Volume of water (before)	Volume of water (after)	Time	Steam Flow rate	
				L/min	L/hr
1	300	279	21	0.54	32.4
2	279	256	23	0.59	35.4
3	256	234	22	0.58	34.8
4	234	214	20	0.51	30.6
5	214	190	24	0.62	37.2
6	270	251	19	0.49	29.4
7	251	228	23	0.60	36.0
Average Steam Flow rate				**0.56**	**33.7**

4.1.2.2 Air Flowrate

The air flow rates were as tabulated in Table 4.2. The average air flow rate was 289 L/min. It has to be emphasized here that the air inlet into the air curtain chamber is $\approx 35^{\circ}C$.

Table 4.2: Air Flow rate Calculation

Exp. / Parameters	1	2	3	4	5	6
Pg_1 (Bar).	9.0	9.8	8.8	9.5	9.2	9.3
Pg_2 (Bar).	7.0	6.9	7.0	7.0	7.0	7.0
Time (s)	69	81	61	76	70	72
Pr_1 (Bar)	2	2	2	2	2	2
Pr_2 (Bar)	2	2	2	2	2	2
HE_1 (°C)	33	33	33	33	33	33
HE_2 (°C)	35	35	35	35	35	35
Air Flow rate (m^3/min)	0.264	0.318	0.264	0.288	0.312	0.288
(L/min)	264	318	264	288	312	288

Legend:

Pg_1 - Initial pressure gauge at compressor

Pg_2 - End pressure gauge at compressor

Pr_1 – Pressure regulator at HE_1

Pr_2 - Pressure regulator at HE_2,

HE – Heat Exchanger

Hence, the mass ratio of steam to air is 0.56 kg steam for every 0.264 kg air, approximately 2 kg of steam per kg of compressed air to maintain the air jet curtain.

4.1.2.3 Pressure Profiles

The pressure profiles along the air curtain chamber were studied for the experimental conditions of C (steam only) and D (steam with air flow). Figure 4.1 and 4.2 show the close-ups of the pressure readings obtained through the data acquisition. As expected the pressure drops drastically the moment steam is injected into the sterilizer. However, a pressure difference of about 2 - 4 mbar was detected in the middle of the sterilizer.

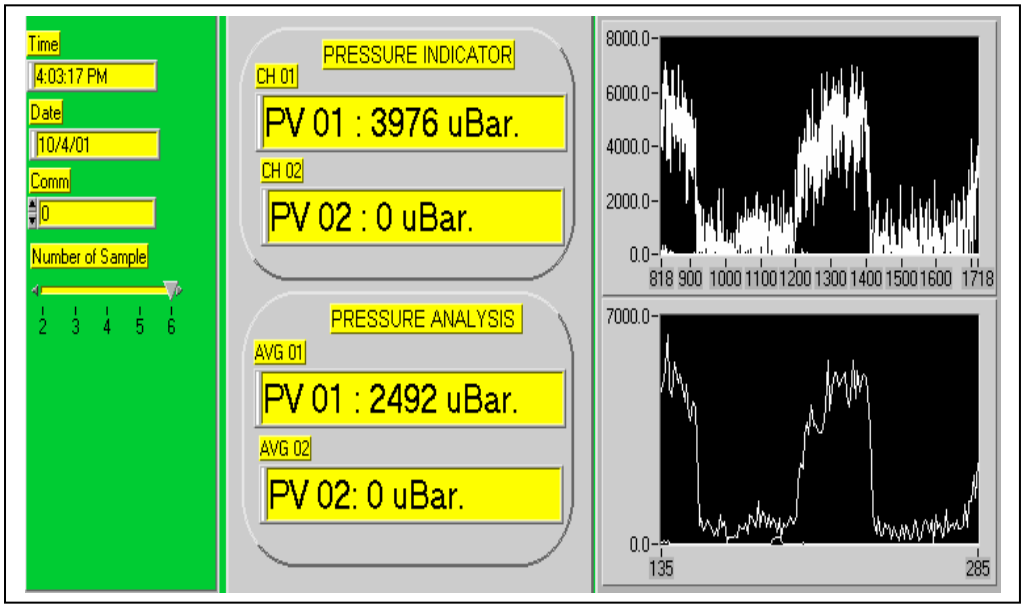

Figure 4.1: Pressure Profile Display

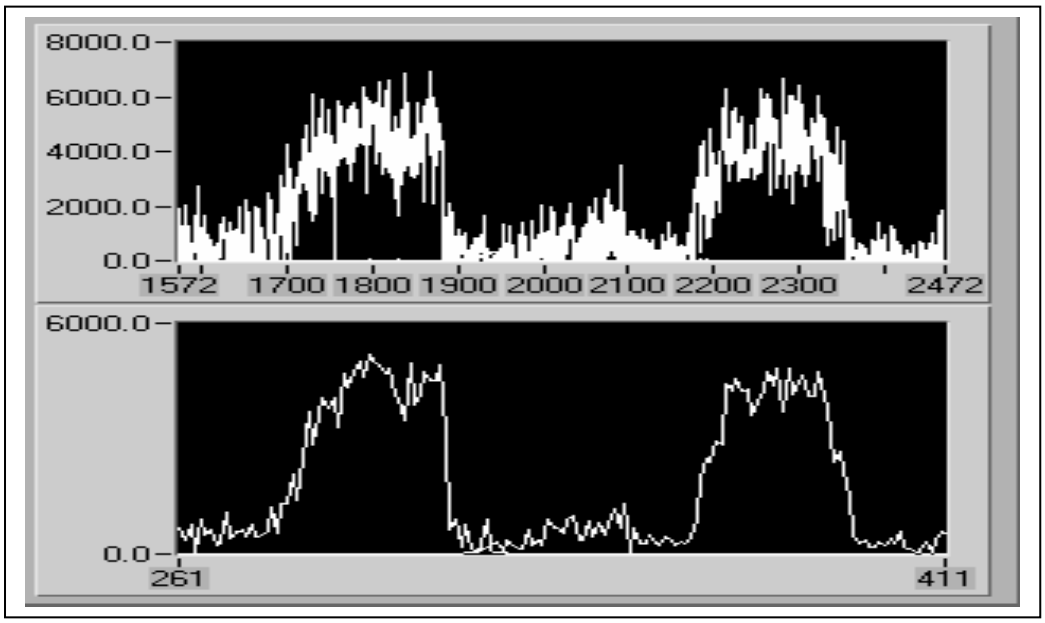

Figure 4.2 : Close-up Pressure Display

Refer to Figure 4.3, the pressure drops steadily to atmospheric pressure. However, there was a slight pressure difference detected within the centre of the air chamber. The use of air in the air curtain chamber causes a slight increased in turbulence within the air chamber

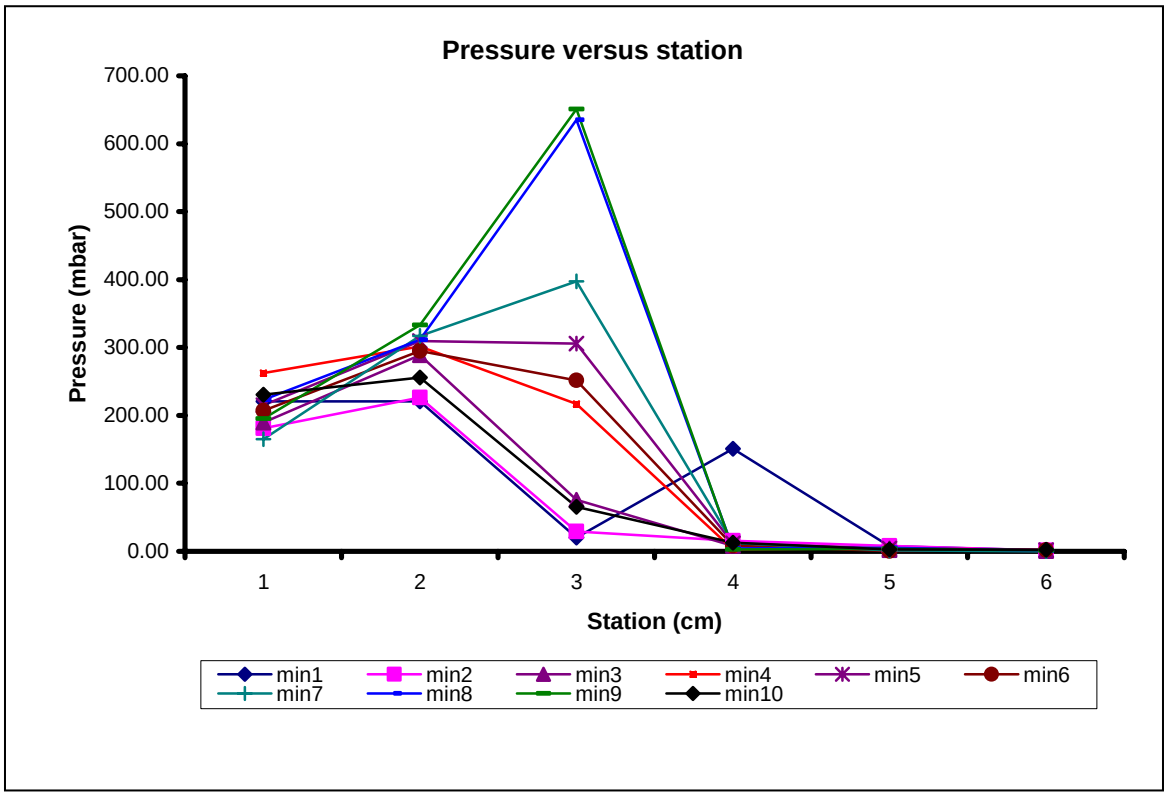

Figure 4.3: Pressure profile vs. location (Experiment E) at Row B (middle) for probe length 6.5cm

4.1.2.4 Degree of Sterilisation in the Experiments.

The sterilisation of the FFB requires a better quantitative measurement. Presently, in previous continuous sterilisation research, the sterilized fruits are visually assessed and this results in inconsistency in the final product.

i) Over-sterilized fruits can he visually observed from the oil that easily oozes out of the excessively soft measocarp. This will result in the excessive loss of oil prior to pressing.

ii) Under-sterilized fruits on the other hand resulted in rather hard mesocarp and the oil yield is rather low.

Therefore, a technique to determine just the right amount of sterilisation is required. Two techniques were being studied here; the use of capacitance and the DSC (Figure 3.7). It can be observed that the three types of sample can be distinguished using the capacitance readings; the fresh samples register readings in the range of 120 - 200 nF, pre-treated fruits have readings of slightly higher 180 - 380 nF and sterilized fruits have a constant reading of 510 nF. The capacitance reading is a quick indicator of checking the various types of fruits. The readings however, cannot distinguish between over or under-sterilized fruits.

The DSC is a much more precise method to indicate the degree of sterilisation as served in the readings. One of the most important parameter is the specific heat capacity (Cp). Water content has a great influence to the heat transfer; the values of Cp are measured in the mesocarp of fruitlets that vary with different water content.

Fresh fruits recorded DSC readings in the range of -5 to -11 milliW at T= 55°C, pre-treated fruits have DSC values of -2.8 to - 3.3 mW and sterilized fruits of -5.2 to -5.9 mW. This method can be further used to establish the value for the desired sterilisation and hence some sort of standard value for the various stage of processing can be established.

4.1.2 Prediction of Size, Time & Velocity of Sterilizer

Optimise the Sterilizer Operating Condition for USB % = 0

Table 4.3: Prediction of Residence to Achieve USB % = 0 at Various Steam Conditions

USB (%)	**Predicted Energy (MJ)**	**Pressure (psia)**	**Opening (fraction)**	**Predicted Time (min)**
70.3824	97.05	15.7	1.000	6.18
8.3591	2000.00	15.7	1.000	127.39
-0.0002	3006.98	15.7	1.000	191.53
10.862	90.00	20.7	1.000	4.35
0	1414.63	20.7	1.000	68.34
22.9946	1557.60	20.7	1.000	75.25
	2500.00	20.7	1.000	120.77

Table 4.4: Prediction of Steam Pressure to Achieve USB % = 0 In 35 Minutes

USB (%)	**Predicted Energy (MJ)**	**Opening (fraction)**	**Time (min)**	***Predicted pressure* (psia)**
70.3824	97.05	2.000	35.0	1.4
8.3591	2000.00	2.000	35.0	28.6
-0.0002	3006.98	2.000	35.0	43.0
10.862	90.00	2.000	35.0	1.3
0	1414.63	2.000	35.0	20.2
22.9946	1557.60	2.000	35.0	22.3
0	2500.00	2.000	35.0	35.7

As seen above, the forecasted residence time to achieve USB % = 0 decreases with increase pressure. In table 4.3, the faster time is achieved for 20.7 psia (≈1.4 bars)

ranged from 68 to 121 minutes conservatively. While at 15.7 psia (≈ 1.1 bar), 192 minutes is required. This duration is about the same as for the figure obtained for boiling the ffb to achieve sterilisation done by KGB Chemara. Penetration is solely dependent on the diffusion of hot water into the fruitlet. On the other hand, in Table 4.4 doubling the flowrate of steam for a fixed period of 35 minutes will required between 2.9 bar to 2.3 bar pressure to achieve USB % = 0.

Both cases assumed that the steam reached the fruitlet at the pressure, amount and the stipulated. In actual case, much steam is dissipated between the entry and the fruit. Furthermore, it also assumed a single layer of fruitlet.

4.1.2.1 Operating Parameters Effect On USB (unstreated bunch)

In short, the effect of better flowrate over the ffb has a small effect on USB compared to the increase in pressure. To illustrate, an increased of 5 psia or 32 % increase in pressure resulted time being reduced to 121 minutes or 59 % reduction. Basically, a 1 % increase in pressure leads to at least 2 % reduction in time. The facts seem to point that the objective of the design of the continuous sterilizer is to maximise the effects pressure and time on ffb to achieve USB % = 0.

4.1.2.2 Correlation Of USB x Energy

From the data obtained from the Bukit Kerayong trials, the amount of ***relative steam energy*** was calculated and correlated against the USB % of the ffb. The absolute amount of steam energy in kilo joules could not be ascertain since there were no accurate steam flowrates of the inlet and outlets and temperatures were not recorded due to lack of instrumentation and preparation by the Bukit Kerayong trial team.

Based on interpolation of the data, each trial produced a particular linear relationship between USB % and energy. This confirmed the overall trend that USB % decreases inversely proportionally to the amount of steam used based on the residence time, pressure, flowrate and temperature.

A more accurate and realistic analysis used extrapolation and non-linear regression of the data to predict the amount of relative steam energy to attained USB % = 0. In this case, at 15.7 psia the amount of steam energy to attained USB % = 0 was more than for 20.7 psia i.e. about 3000 units for the former and 2500 units for the latter (Table

4.3 & 4.4). In the other case, the amount of relative steam energy of 20.7 psia at longer time residence of 60 minutes used less steam energy than 20.7 psia at twice the steam flowrate. This indicated that the effect of time and pressure of the steam has a more profound effect than increasing the flowrate of steam. Conversely, in a continuous system, time and pressure are more critical parameters than flowrate. This confirmed the model findings that penetration is solve by dependent on the diffusion of steam into the fruitlet and not on the amount of steam available.

4.1.2.3 Continuous Sterilizer Design Concept Impact on USB

The crux of the matter is that sterilisation is achievable at the minimum of 20.7 psia or 1.5 bar absolute (0.5 bar gauge). This was achieved in the ***Bukit Kerayong*** prototype by using baffles to increase residence time and pressure. However, the inclusion of baffles in a screw conveyor or conveyor belt continuous sterilizer is problematic and entails a complex design.

Alternatively, CLEAR favour a continuous sterilizer using the fluidised bed concept to achieved 1.5 bar at the entry of steam into the bottom of the vessel to fluidise the ffb and flashing at 1 bar in the vessel. The constraint is that ffb is very difficult to fluidise but it should work efficiently once the stalk are stripped off. As mentioned earlier, the stalk effectively absorbed more heat and divert it away from the fruitlet. Conversely, if 1 bar absolute pressure is to be expected then the residence time with be about 192 minutes or longer than the typical batch sterilizer duration of 90 minutes. The immediate impact is that capacity must be enlarged since sterilisation time is doubled which effectively halving capacity.

In order to sustain a production target of 60-tonnes/hr ffb for 1 atm process, the continuous sterilizer must process 192 tonnes/hr over 3.2 hour continuously. Effectively, this means that the capacity of the sterilizer must increase by 3.2 times which means the increase in size, flowrate and utilities requirement.

This production line would be consuming more steam not only to sterilize 192 tonnes/hr but also to maintain continuous pressure and overcome heat and pressure losses in the system since it is open to the atmosphere. On this same basis, the size of the continuous sterilizer will be huge much larger than the equivalent batch sterilizer operating at 4 bar and 35 minutes. Consequently, a batch sterilizer operating at 4 bars and 35 minutes will be cheaper and more sensible.

The most economical solution is to operate at 1.5 bar absolute and attained duration of 68 minutes, which is still shorter that the batch sterilizer duration of 90 minutes and increase throughput. In this case, the production capacity is 52.9 tonnes/hr which means that to sustain 60 tonnes per hour, 68 tonnes per hour must be continuously sterilised. This is about an increase of 1.13 times the average production rate and would not entail a smaller sterilizer and utilities requirement than the 1 bar option.

The critical question now is how we attain 1.5 bar continuous sterilisation without classifying the vessel as a pressure vessel. On this matter perhaps the fluidisation bed or steam spray sterilizer is suitable. The next question is how we keep the size small and the flowrate of PTF fast so that an average production rate of 60 tonnes per hr can be attained.

Essentially, the increase in capacity and time would mean larger, longer sizes and more utilities will be consumed. There is a limit to the size of the sterilizer when it is deemed uneconomical.

4.1.2.4 Energy Consumption & Conservation In Sterilizer

To sustain a production target of 60-tonnes/hr ffb for this process, the continuous sterilizer must process 192 tonnes/hr over 3.2 hour continuous sterilisation. Effectively, this means that the capacity of the sterilizer must increase by 3.2 times which means the increase in size, flowrate and utilities requirement.

Assuming an average of 50 kg of steam per tonne ffb process from typical mill steam consumption, this production line would be consuming more steam to sterilize 192 tonnes per hr as well as to maintain continuous pressure and overcome heat and pressure losses in the system since it is open to the atmosphere.

In order to maintain sterilisation the amount of 9,600 kg of steam per hour. Since the system is open, the loss of steam is calculated to be 60 % of the incoming heat hence actual steam required is 16,000 kg of steam.

4.1.3 Heat loss on sterilizer

Sterilization + PTP 20 min (80-90°C) + Steam Curtain				
Time	CH2	CH3	CH4	CH5
0	86.0	83.9	85.8	82.8
5	99.0	99.0	98.4	98.4
10	99.3	99.3	97.9	98.0
15	99.5	99.7	98.0	97.9
20	99.4	99.5	98.4	98.5
25	99.0	99.3	97.8	98.2
30	99.6	99.4	98.5	99.0
35	99.8	99.6	98.5	99.0
40	99.3	98.7	97.6	97.8
45	99.8	99.8	98.9	99.3
Average	98.1	97.8	97.0	96.9
T (K)	371.3	371.0	370.2	370.1
Steam flowrate : 1.04 L/min				
T (K)	v (m2/s)	k	Pr	σ
298.15	1.12E-05	0.01846	1.142	8.15E-06
371.3	2.056E-05	0.02395	1.068	1.9E-05
371.0	2.052E-05	0.02393	1.069	1.9E-05
370.2	2.042E-05	0.02387	1.07	1.9E-05
370.1	2.041E-05	0.02386	1.069	1.9E-05

Sterilization + PTP 20 min (80-90°C) + Hot air Curtain				
Time	CH2	CH3	CH4	CH5
0	27.0	25.0	26.5	27.9
5	82.7	75.3	73.8	71.7
10	84.9	78.4	77.4	75.5
15	86.6	79.9	78.7	75.9
20	86.2	80.2	78.9	78.4
25	86.2	80.8	79.0	78.4
30	86.4	81.7	78.9	78.3
35	86.1	81.4	79.3	78.5
40	86.6	81.8	79.4	79.0
45	86.2	80.9	78.6	78.1
Average	79.89	74.54	73.05	72.17
T (K)	353.1	347.7	346.2	345.4
Steam flowrate : 1.04 L/min				
T (K)	v (m2/s)	k	Pr	σ
298.15	1.12E-05	0.01846	1.142	8.15E-06
353.1	1.822E-05	0.02258	1.086	1.64E-05
347.7	1.753E-05	0.02218	1.092	1.56E-05
346.2	1.734E-05	0.02207	1.094	1.53E-05
345.4	1.724E-05	0.022	1.095	1.52E-05

Sterilisation +PTP 20 min (100°C)+Steam Curtain				
Time	CH2	CH3	CH4	CH5
0	99	98.1	97.1	96.5
5	99.1	98.8	97.1	96.8
10	99.4	99.5	97.5	97.8
15	99.4	99.6	97.9	97.8
20	99.7	99.6	97.9	98.3
25	99.8	99.6	98.5	98.3
30	99.9	99.7	99.9	99.1
35	99.8	99.8	99.9	99.8
40	100	99.9	99.9	99.8
45	99.9	99.9	99.9	99.8
Average	99.60	99.45	98.56	98.40
T (K)	372.8	372.6	371.7	371.6
Steam flowrate : 0.96 L/min				
T (K)	v (m2/s)	k	Pr	σ
298.15	1.12E-05	0.01846	1.142	8.15E-06
372.8	2.075E-05	0.02406	1.067	1.932E-05
372.6	2.071E-05	0.02404	1.065	1.930E-05
371.7	2.062E-05	0.0240	1.063	1.925E-05
371.6	2.060E-05	0.02399	1.061	1.924E-05

Sterilisation +PTP 20 min (100°C)+Hot Air Curtain				
Time	CH2	CH3	CH4	CH5
0	28.8	26.4	29.4	29.4
5	85.0	70.4	68.1	65.8
10	86.7	75.8	74.6	72.5
15	87.0	76.2	75.2	73.0
20	86.5	76.2	75.1	73.1
25	87.3	76.5	75.3	73.7
30	87.7	77.4	76.5	74.7
35	81.8	77.5	76.5	75.0
40	87.5	77.8	76.6	74.6
45	87.7	77.9	76.6	75.0
Average	80.6	71.21	70.39	68.68
T (K)	353.8	344.4	343.6	341.9
Steam flowrate : 0.96 L/min				
T (K)	v (m2/s)	k	Pr	σ
298.15	1.12E-05	0.01846	1.142	8.15E-06
353.8	1.831E-05	0.02264	1.086	1.647E-05
344.4	1.711E-05	0.02193	1.096	1.506E-05
343.6	1.700E-05	0.02187	1.097	1.494E-05
341.9	1.678E-05	0.02174	1.098	1.469E-05

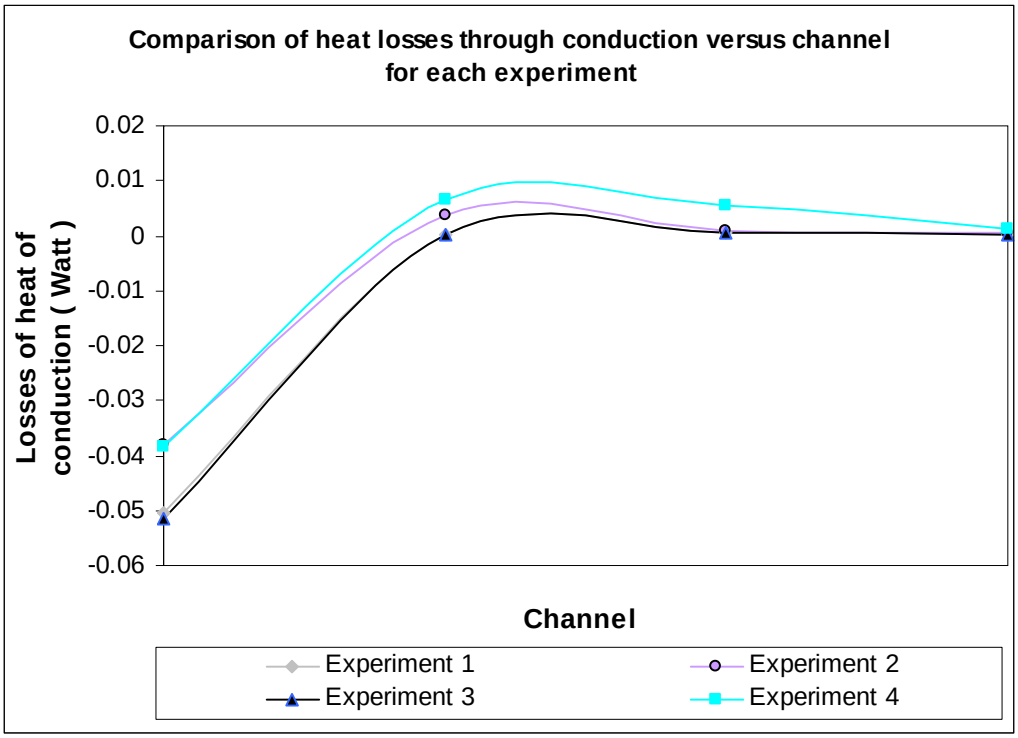

Figure 4.4: Comparison of heat Losses through conduction versus channel for each experiment

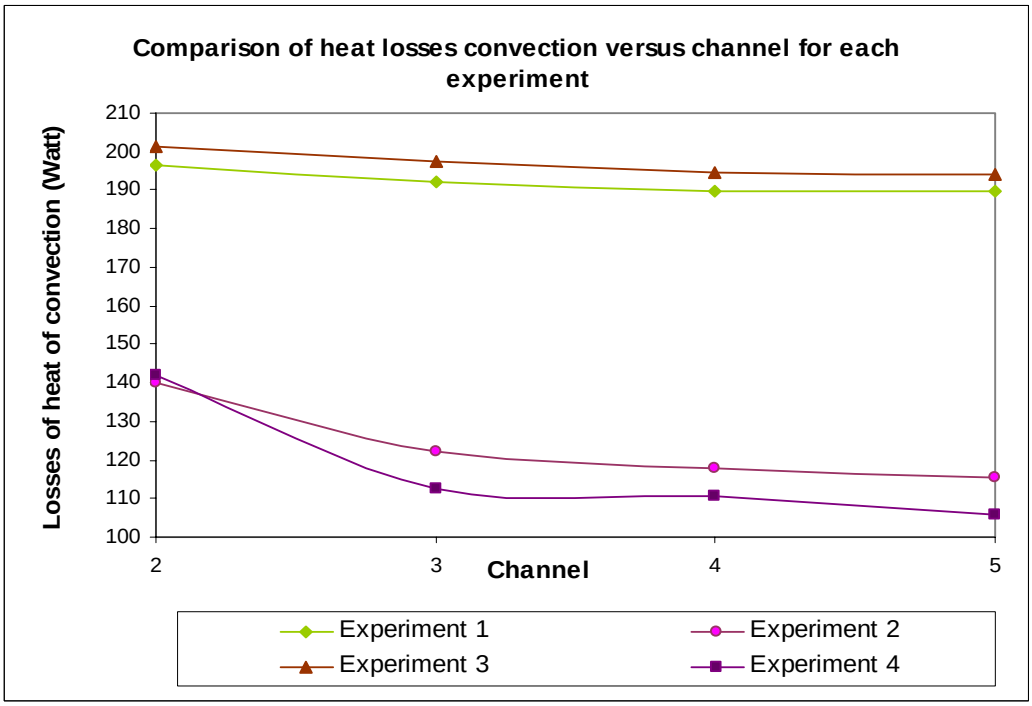

Figure 4.5 : Comparison of heat losses through convection versus channel for each experiment

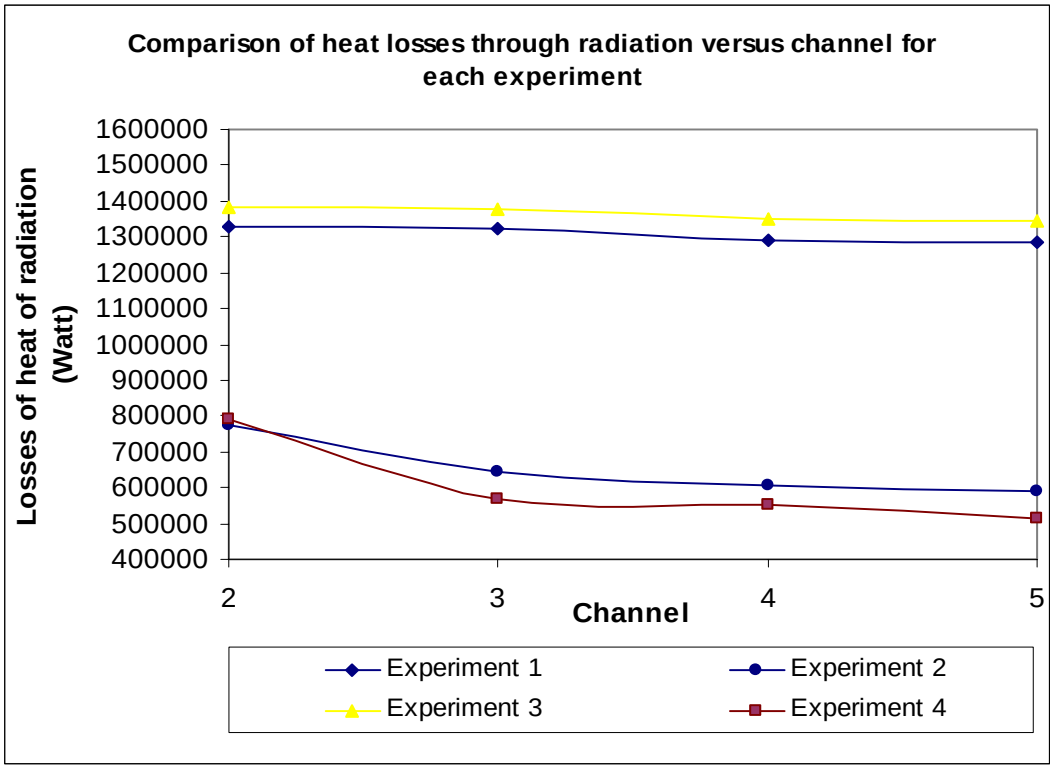

Figure 4.6 : Comparison of heat losses through radiation versus channel for each experiment

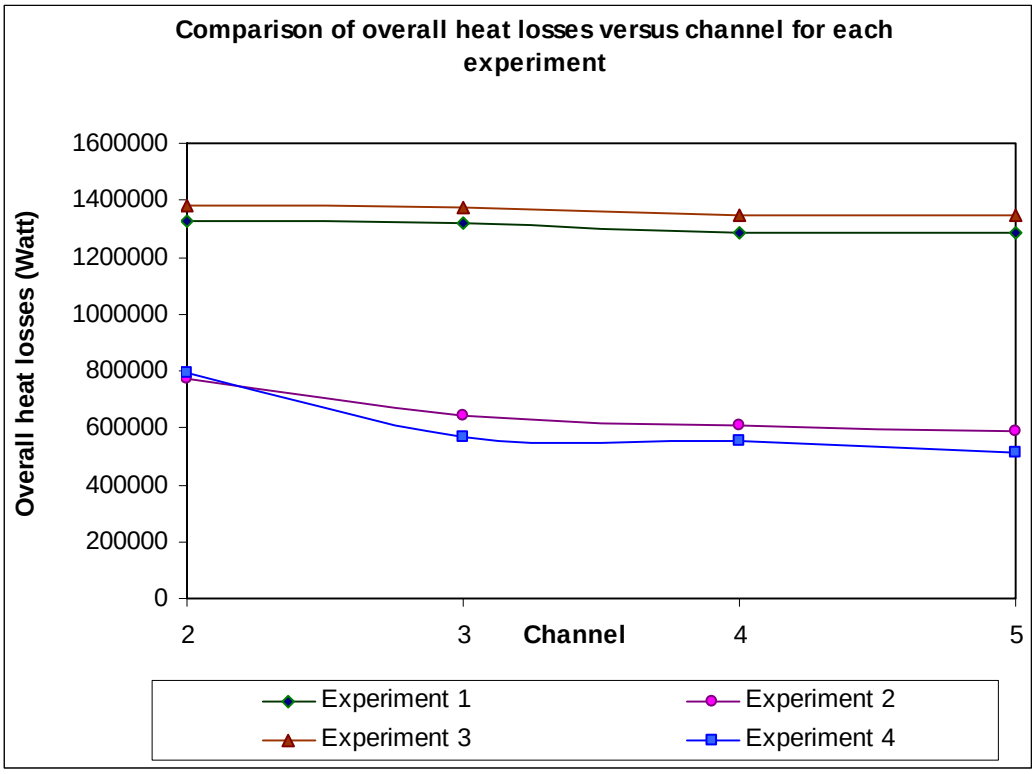

Figure 4.7 : Comparison overall of heat losses versus channel for each Experiment

4.1.3.1 Heat Losses of Conduction

Based on the equation, it is derived that temperature is proportional with heat. Therefore, it can be observed that either at 80°C Pre-Treatment Process (PTP) or even at 100°C PTP, the heat losses of hot air curtain is lower compare with the situation for steam curtain. This is because the channels' overall temperature for the experiment which employ hot air curtain is low (between 70°C to 80°C) while for the steam curtain, the temperature is approximately or more than 100°C (close to water boiling point).

The losses of conduction heat in sterilizer with the use of steam curtain are low due to the proportional relationship between temperature and heat. For that reason, the heat losses are

low when the temperature is low. Dissimilar condition happened to the experiment which employ steam curtain. At high channels' temperature, heat losses is also high.

From figure 4.4, it shows a negative curve at the point of channel 2 and channel 3 due to the conduction which happened at the opposite flow. It is possibly because there is channel 6 situated between channel 2 and channel 3 which it's function is to detect the overall temperature.

As the steam or air leave the nozzle at each channel, this exit steam or hot air at channel 6 will disturb the exit steam at channel 2 and 3, results to the disruption of that part and backflow. While at channel 5 for each experiment, the heat losses is high because of the huge difference with the surrounding temperature.

A. Losses of Heat of Convection

The comparison of heat losses through convection is shown at figure 4.5. There is significant difference of the results between the steam curtain and hot air curtain. This is because the outside part of the sterilizer is insulated with fiber to prevent the steam or heat from exit to the surrounding. This is to ensure that the fresh palm fruits will fully cook in the sterilization process. In addition, it will affect the heat losses from the steam curtain and hot air curtain as well as providing the high difference of losses towards the steam curtain.

Hot air curtain at 100°C PTP have low heat losses compared with 80°C PTP. This is because PTP also influence the value of heat losses. At 100°C PTP, the value of Cp for oil is higher than 80°C, results to the high losses of oil during the process. Consequently, water filled the space or part to offset the losses of the oil. During the process of sterilization, the oil fruit sample will absorb more heat to remove the water. As a result, the heat in the sterilizer is high and less of the volume will exit to surrounding compared with the process at 80°C PTP.

B. Losses of Heat of Radiation

From observation, figure 4.6 showed. It has the low value of losses and thus is negligible. This is due to the temperature factor that can be observed from the channels.

C. Overall Heat Losses

After combining all the value of heat losses from the losses of heat of conduction, heat of radiation and heat of convection, the graph which shows the difference between overall heat losses versus channels if plotted. The plots for experiment 2 which employ hot air curtain at 80°C PTP show the lowest heat losses followed by experiment 4. While, the steam curtain experiment at 100°C PTP shows the highest losses.

To identify the overall losses through the channels, figure 4.7 is plotted in which the value of overall heat losses is accumulated.

4.2 Differential Scanning Calorimeter (DSC)

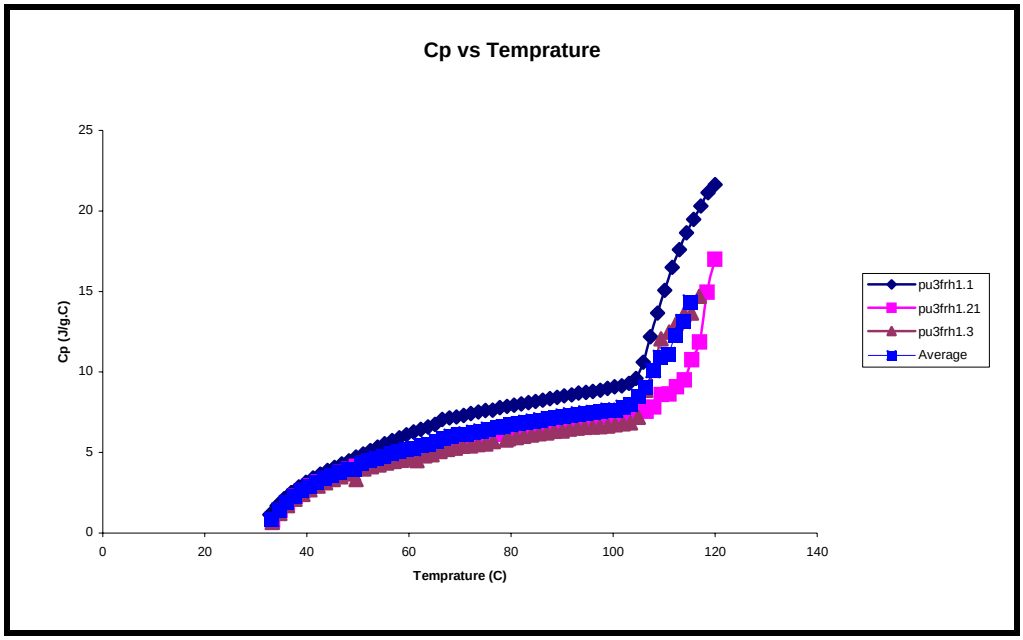

Figure 4.8 : Cp versus Temperature

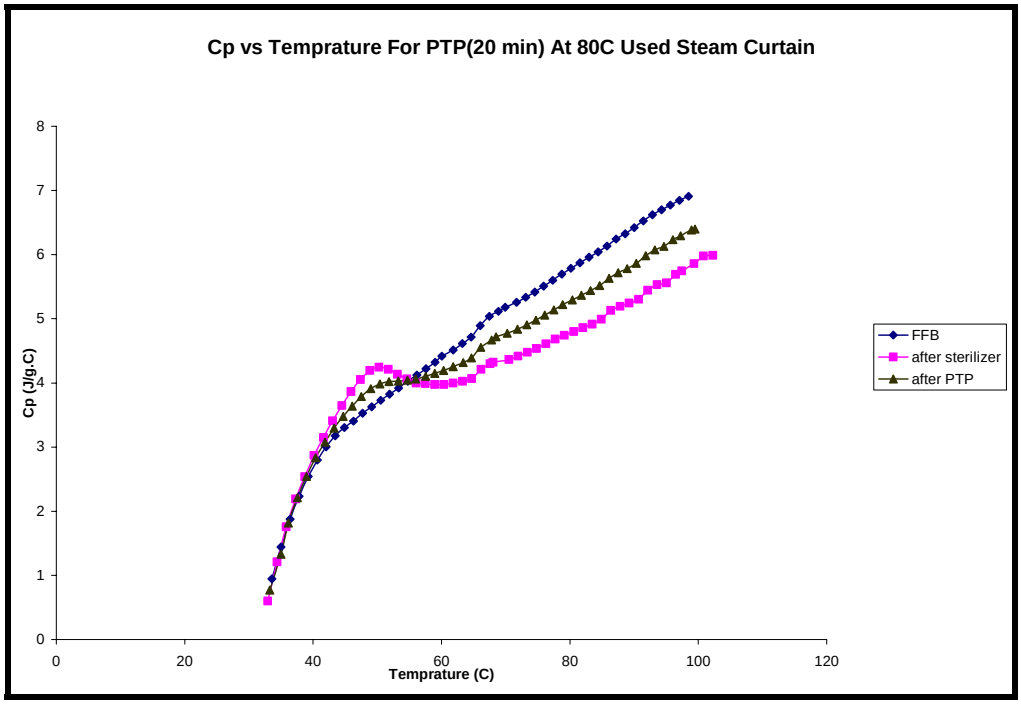

Figure 4.9 : Cp versus Temperature for PTP 20 min used steam curtain

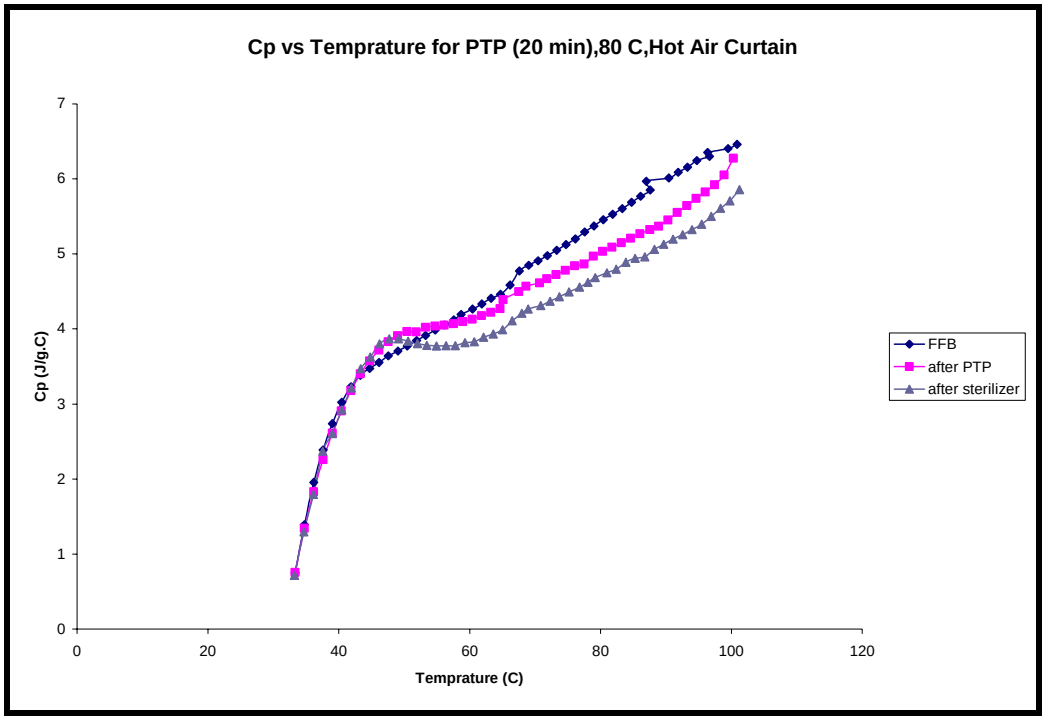

Figure 4.10 :Cp versus temperature for PTP 20 min (80°C)used hot air curtain

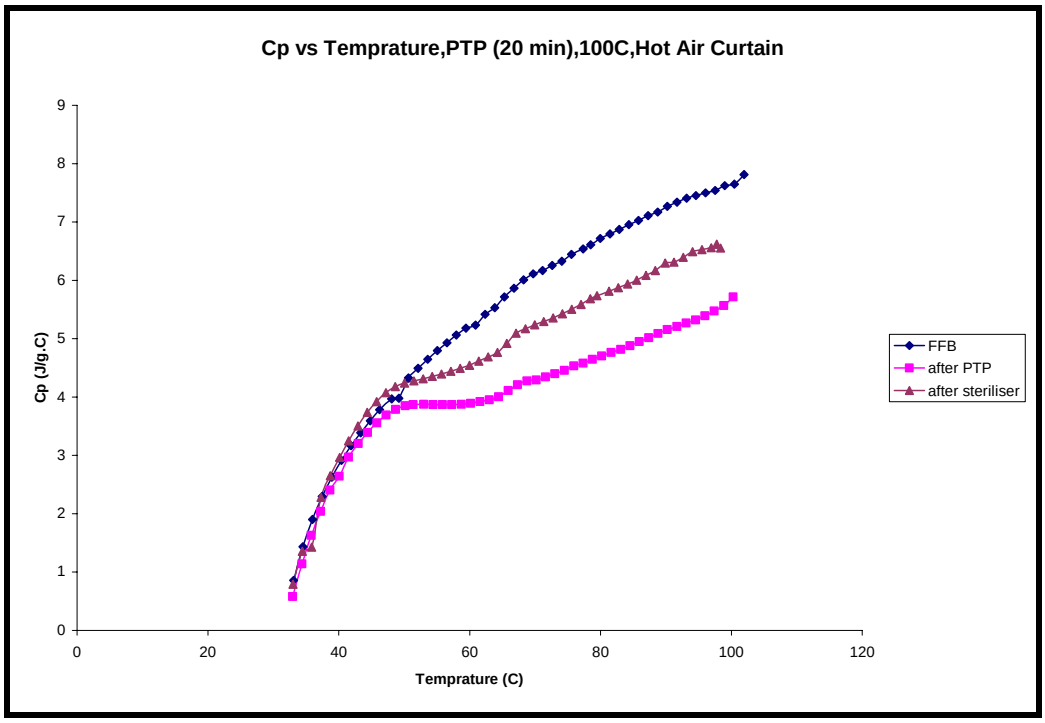

Figure 4.11 : Cp versus temperature PTP 20 min (100°C) used hot air curtain

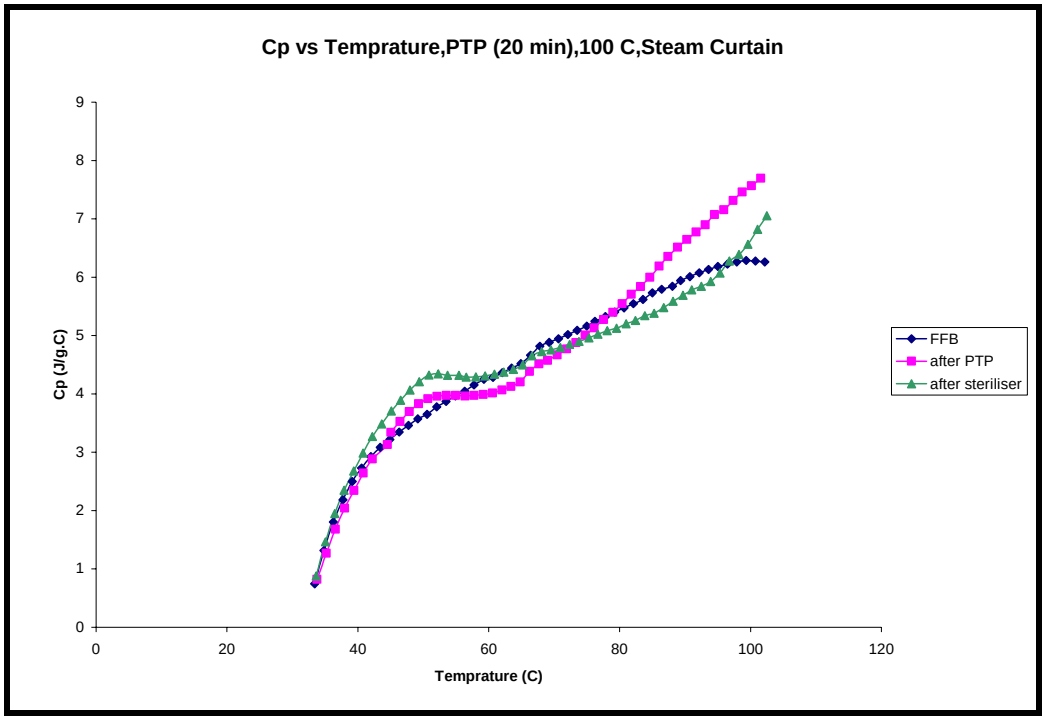

Figure 4.12 : Cp versus temperature PTP 20 min (100°C) used steam curtain

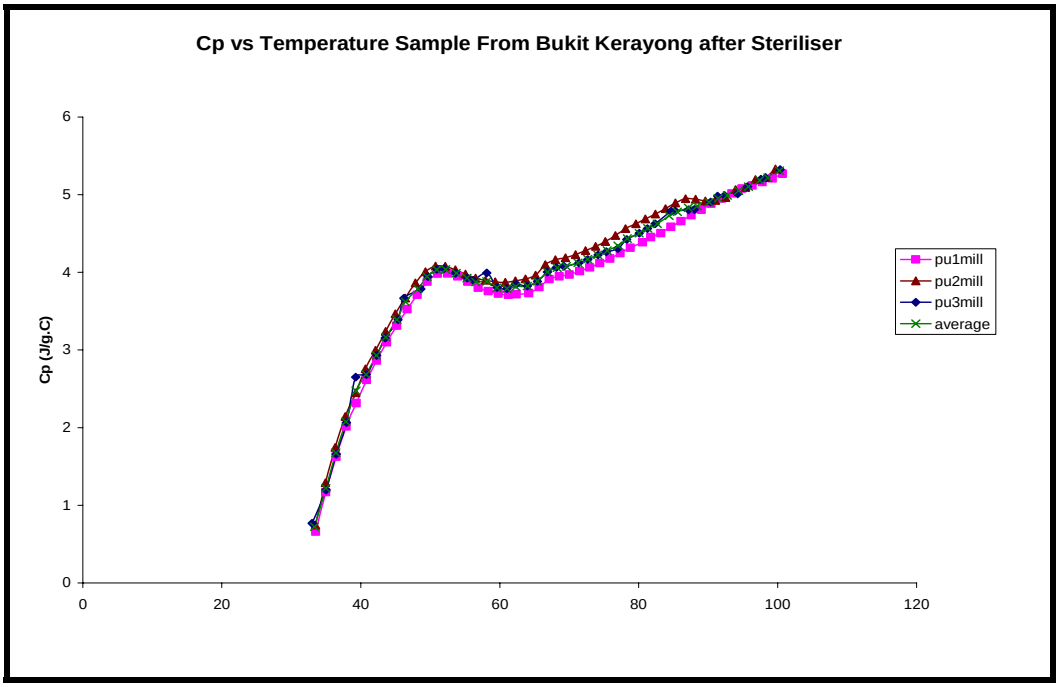

Figure 4.13 : Cp versus temperature sample from Bukit Kerayong after sterilizer

4.3 Results & Discussion On The Sensitivity Analysis Result

4.3.1 Heat Capacity or Specific Heat

Thermal properties for food play an important role in the quantitative analysis of food processing operations. In a processing system, it is necessary to predict the end point of processing to ensure the quality of the food product and the efficiency of the equipment. All processing time prediction models need thermal properties data of food where energy transfer is involved.

Specific heat of a food material is a measure of amount of energy required by a unit mass to raise its temperature by a unit degree. Specific heat, or the mass heat capacity of food materials, has been determined experimentally by several methods, including the method of mixtures, method of guard plate and using a differential scanning calorimeter (***Choi & Okos, 1986***). The temperature of the sample in the DSC cell was increased at a constant heating rate for measuring the specific heat of substance. One of the most important findings in this study was the heat capacity of the mesocarp for fruitlet under difference conditions. The heat capacity or specific heat of mesocarp under difference conditions is shown in figure 4.1

The overall results show an increase in heating rate with increasing temperature and time. The results showed that the heat capacity of pretreated fruit (PTF) with various water contents have a different value compared to fresh fruit (FF). It can be seen that the when PTF was heated between 10 – 20 minutes, Cp for 10 minutes boiling (PTF+10) was 6.47 kJ/Kg^{o}K.

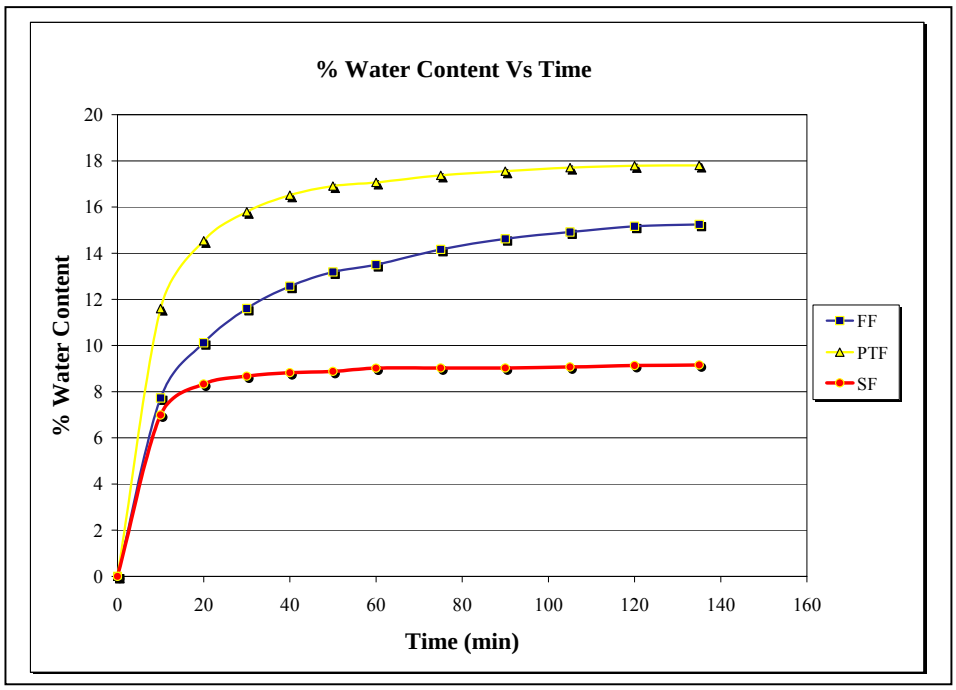

Figure 4.14 : % water content versus time

(PTF+20) was 6.68 kJ/Kg^{o}K and (PTF+30) was 5.313 kJ/Kg^{o}K. Cp increased with increased in water content but after 30 minutes boiling in hot water at (PTF+30), the value of specific heat slowly decreased, towards the Cp of a sterilised fruitlet mesocarp.

It was predicted, based on these data, that the water inside the fruit (mesocarp) had vaporised and the fruit was slowly saturated with oil since it is known that the specific heat of water are higher than crude palm oil. The presence of water inside the fruitlet (mesocarp) increase the values of specific heat whilst oil decreased it.

During the literature review, the difference between the experimental values and ***Dr. Masitah*** values for fresh fruit (mesocarp) was probably due to the fatty acids content. As mentioned before, ***Dr. Masitah*** froze the sample to 4^{O}C but the ***Mongana Report*** has reported that oil frozen would produced a higher fatty acids percentage and affect Cp.

As we can see, sterilised fruit have the lowest values of specific heat due to the fact that it was already saturated with oil or, conversely the water was fully vaporised out of the fruitlet.

Many factors affect the results of the specific heat, for example, temperature rise during a DSC test increases vapour pressure within the sample and as a result, moisture may escape from the biological material in the form of water vapour. The latent heat absorbed in the process with introduce error in the measurement. Thus, sample encapsulation or sample pan sealing was used to get a good result (***Mohsenin, 1980; Tang et. 1991***).

4.3.2 Water Content

The percentage of water loss for three differences fruit mesocarp. Percentage water content for FF was 15%, PTF was nearly 18% and SF was 9%. Our experimental results were contradictory to the Mongana Report because in this experiment studied the mesocarp but the Mongana Report reported on measurement for one fresh fruit bunch.

From Pretreated Fruit (PTF) curve, it can be seen that it has a higher percentage of water than the Fresh Fruit (FF) and Sterilised Fruit (SF) because the fruitlet already saturated due to soaking in water at 80^{o}C temperature maintains for 30 minutes.

4.3.3 Heat Transfer Coefficient

The figure 4.15 shows the effect of heat transfer coefficient on the time of sterilisation process. Heat transfer coefficients determined was the heat transfer coefficient of steam used for the sterilisation process. It was found that with the increased in the steam pressure, There was an increased in the heat transfer coefficient which shorten the process. This is an expected since the higher heat transfer coefficient will shorten the time to complete the sterilisation process.

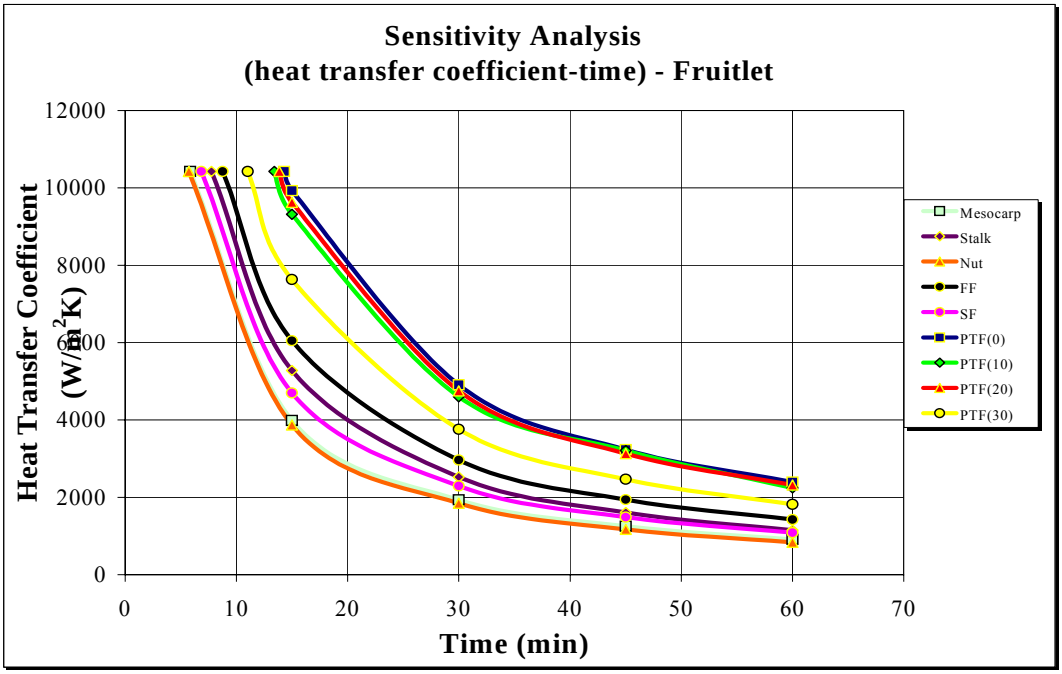

Figure 4.15 : Heat transfer coefficient versus time

This graph is related to the USB % vs. energy graph obtained from field experiments. The higher the heat transfers coefficient hence the lower the USB % obtained. In this case, high heat transfer coefficient obtained by better heat penetration, water content, temperature, pressure and time will decrease USB at a faster rate.

4.3.4 Thermal Diffusivity

Thermal diffusivity used is to estimate the processing time of canning, heating, cooling, freezing, cooking, frying or sterilising. Thermal diffusivity of a food material is affected by both water content and temperature, as well as composition and porosity (***Singh, 1982***).

Moisture content in food and temperature changes considerably during the food processing operations affect thermal diffusivity. ***Singh (1982)*** found that temperature and water content are the major factor affecting thermal diffusivity when investigated the influence of water, fat, protein, carbohydrate and temperature. Variation of the solid fraction of fat, protein and carbohydrate had a small influence on thermal diffusivity. ***Han & Loncin (1985)***

reported that the influence of lipid on the thermal diffusivity could be neglected without any significant errors in the practical industrial sterilisation.

Relationship between thermal diffusivity with time during sterilisation process. It showed that the thermal diffusivity values for different type of mesocarp are almost horizontal line with increasing the sterilisation time. In this situation, the sterilisation time did not affect the value of thermal diffusivity if the bulk of fruitlet is past through the sterilizer.

4.3.5 Time Step

figure 4.16 shows the effect of sterilisation period on the time step. For all type of mesocarp, the value of time step are constant hence the sterilisation time is not affected by the change of the time step. It is important to note that with increasing the sterilisation time, the value of time step also increase linearly.

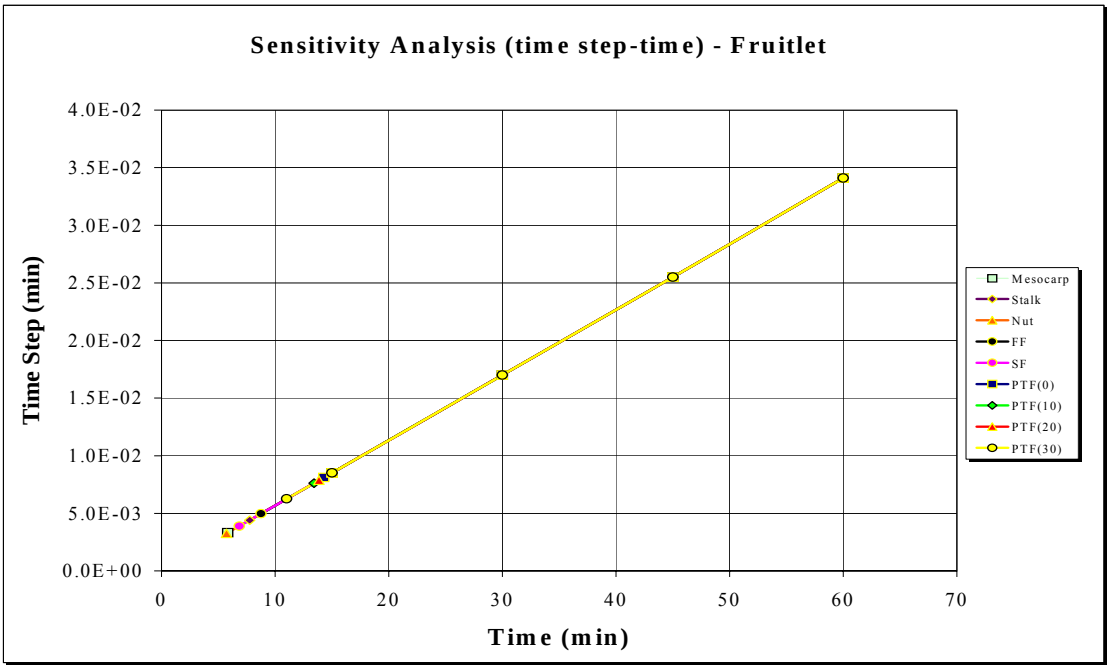

Figure 4.16 : Sensitivity analysis time step time

4.3.6 Final Temperature-Time

Final temperature versus heat transfer coefficient steam. From these plots, it is observed that the final temperature for sterilisation process raised gradually with time until it reaches limiting temperatures.

As we can see, the temperature profiles are different with different type of conditions of mesocarp. As the pressure increase, the final temperature also increase. Since the nut and stalk have similar times to achieve maximum temperature, it means that in a mixture dominated by the stalk, it will absorb the most heat and divert it from the fruitlet. Therefore, the presence of the stalk increases the sterilisation time. The nut too has the same effect but is insulated by the kernel in mesocarp of the fruit.

4.3.7 Final Temperature- Heat Transfer Coefficient

Final temperature (target temperature for sterilisation) versus time. It can be seen that the heat transfer coefficient decrease as the final temperature increase. In this case, the steam pressures was varied from 1 bar to 4 bar, all samples have the same heat transfer coefficient profile at the starting point except for stalk and nut which have a higher heat transfer coefficient at the end of the process.

One of the most critical findings was that different water content inside the fruitlet mesocarp does not effect the value of heat transfer coefficient of the steam.

4.3.8 Result Correlated

The experimental results of heat capacity were then used in the computation of heat penetration model. Thereafter the result of the model was used to predict the residence time of sterilisation for continuous process purposes.

CHAPTER V

CONCLUSION AND RECOMMENDATION

Historically, this prototype design and calculation was based on the mathematical model and design study of the continuous sterilization by steam and heat penetration presented in 1999 by (Mustafa & Halim, 1999).

Specifically, this paper has concluded that hot water and hot air are effective means to retain sterilization steam during sterilization process. The results also suggest that a thermally insulated jet curtain chamber is required to maintain thermal integrity to retain the thermal and pressure effectiveness of the locking fluid against the escaping sterilizing steam. This will increase the efficiency of the trapping process.

Furthermore, heat capacity and capacitance measurements can be used to check the degree of sterilization. Further trials on capacitance and heat capacity are required to establish the standards for various processing conditions.

A mathematical and computer model of a heat penetration or heat distribution for continuous sterilizer, concentrating on one fruitlet has been developed. The program is capable of predicting the optimum condition for sterilization. Initial results indicate the potential of using such a computer program in the design of a continuous sterilizer.

The prediction of the operation condition for the sterilization process of a fruitlet was based on a heat transfer by conduction model. The prediction results clearly or approximately showed that the time for the mesocarp to attain thermal equilibrium with the steam temperature.

It does not indicated the time required to sterilized the fruit to attain USB % = 0 %. To obtain the sterilization time, experimental data from a field trip prototype of the sterilizer was used. Based on this result, it was found that a minimum pressure of 1.2 bar at 60 minutes was sufficient to sterilize the pretreated bunches to achieved USB = 0 %. Comparing the result in as mention above, the optimum time to sterilize a fruitlet (or mesocarp) is 120°C, 1,2 bar for 60 minutes.

However, there is a need to reduce these operating conditions further to allow the design of a non-pressure vessel sterilizer to sterilize pretreated fruit.

To do so, the definition of sterilization measured by USB % cannot be used as an objective measure of sterilization to be applied to a single fruitlet after being pretreated. Heat capacity was chosen to measure sterilization by virtue of the effects of sterilization with after the physical and chemical nature of the fruitlet. These irreversible alterations will change the thermal properties can be measured by heat capacities. However the measurement of heat capacities must be conducted very carefully to prevent error.

The Cp of the fresh fruitlets (not FFB), sterilized fruitlets and pretreated was measured. To study the effect of percentage of water content and heat on the PTF, the PTF was boiled in hot water for 10, 20, 30 minutes and heat capacity measured respectively. It was found that for 10, 20 minutes boiling after PTF, heat capacity increase, due to the water content in the PTF brought about by boiling the hot water. After 30 minutes, the boiling has affected the nature of the PTF causing a lowering of heat capacities. Probably caused by water diffusing out from the fruit and the mesocarp being altered by boiling. If the result was extrapolated/interpolated with the sterilized fruits heat capacity, it would indicate that boiling of PTF for 10–20 minutes merely increase percentage of water content but not the nature of the fruitlets.

At 30 minutes or more, the PTF nature is altered by boiling and percentage of water content is reduced, (possibly oil being liquefied) and displacing the water resulting in the heat capacity lowering towards sterilized fruit heat capacity. At this point it could be deduced that the PTF has under gone some measure of sterilization.

Therefore, PTF after 30 minutes boiling could require another 30 minutes for full sterilization by the Bukit Kerayong experiment results or other 15 minutes by model results. The impact of this experiment showed that by boiling the PTF prior to sterilization, sterilization time can be reduce from 60 minutes to possibly 15 minutes. Taken together, the

pretreated fruit takes 30 minutes + 15 minutes (model), so that the total sterilization time is 45 minutes theoretically.

An initial result indicates the potential of using such a computer program (spreadsheet modeling) in the design of a Continuous Sterilizer.

From the data and graphs which have been plotted for each experiment, it can be conclude here that the utilization of hot air curtain at 80°C shows the lower heat losses compared with the condition for steam curtain. This can be confirmed according the graph 4 which represent the overall heat losses. Nevertheless, the results for the experiment which employ hot air curtain at 80°C PTP and at 100°C PTP are almost close to each other. However, various factors should be taken into consideration before any decision is to be made. Based on the observations during the experiments including the initial stage which is the fruit cutting process till the final sterilization process, it shows that many losses happened while the PTP is being conducted. It happened at the temperature around 100°C. Perhaps, the oil losses also happened in the sterilizer itself due to the high temperature. This research results show that the suitable temperature for the oil fruit to fully cook in which the lipase enzyme can be deactivate to reduce the fatty acid is around 80°C. It can be presumed that, the quality and the quantity of the oil produce will reduce and then affect other additional factors such as economy aspect. Despite, the temperature for the utilization of hot air curtain at 80°C PTP is appropriate to ensure that the oil fruit is fully cooked.

The offset form plastic curtain to rubber curtain is an alternative to assure fewer losses in sterilizer. As far as we concern, the rubber curtain have a good insulation characteristic compared with plastic. Even the cost for the rubber curtain is more expensive than the plastic curtain; it can ensure an excellent quality and quantity of the oil that will be produced.

Other than that, the thickness of the cylinder is also one of the factors that should be considered in order to reduce the losses in sterilizer. This is because the existing sterilizer have cylinder with the thickness of only 0.01 mm. This will contribute to the dispersion of heat to surrounding. Moreover the cylinder is made of steel which can easily lead the heat to disperse to surrounding.

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APPENDIX

The data have been taken after process sterilization with various method to get the best value of temperature to cook the fresh fruit bunch (FFB) .

Table A1: Sterilization +PTP 20 min (80-90C)+Steam Curtain

Time	CH1	CH2	CH3	CH4	CH5	CH6
0	92	86	83.9	85.8	82.8	90
5	99.4	99	99	98.4	98.4	99.3
10	99.7	99.3	99.3	97.9	98	99.4
15	99.6	99.5	99.7	98	97.9	99.7
20	99.8	99.4	99.5	98.4	98.5	99.5
25	99.5	99	99.3	97.8	98.2	99.2
30	99.8	99.6	99.4	98.5	99	99.6
35	99.5	99.8	99.6	98.5	99	99.7
40	99.8	99.3	98.7	97.6	97.8	99.4
45	99.9	99.8	99.8	98.9	99.3	99.8

Steam flowrate: 1.04 L/min

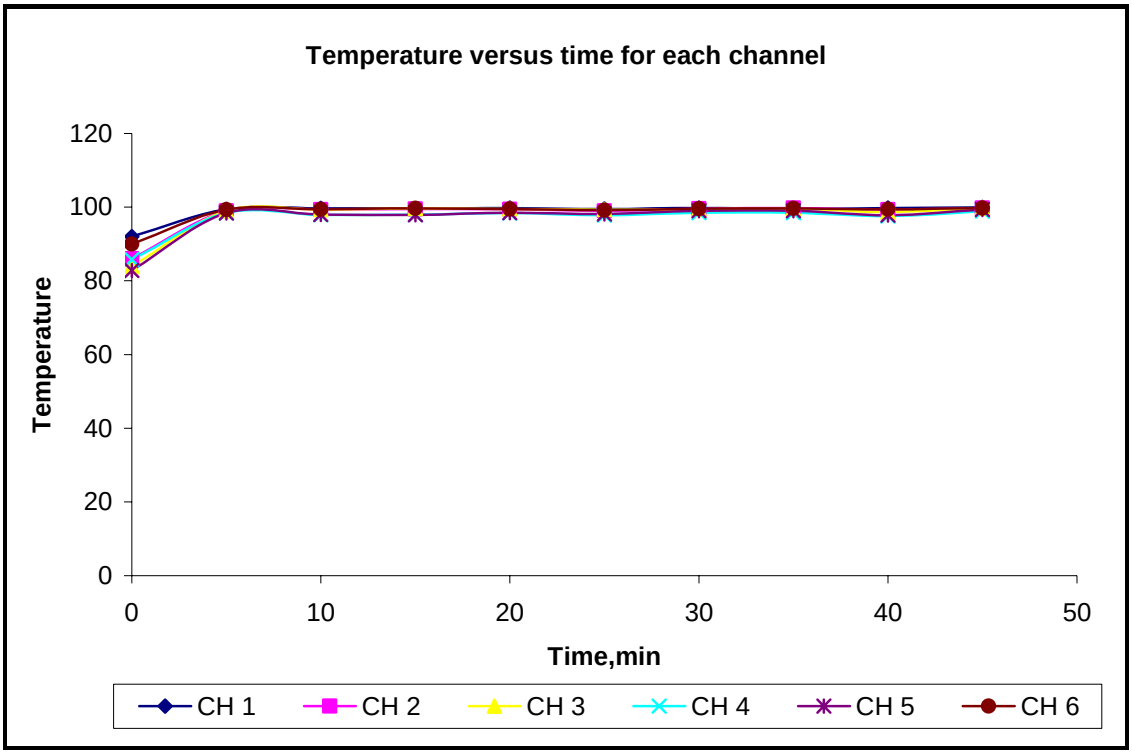

Figure A1: Temperature versus time for each channel

Table A2: Sterilization +PTP 20 min (80-90°C)+Hot Air Curtain

Time	CH1	CH2	CH3	CH4	CH5	CH6
0	29	27	25	26.5	27.9	27.5
5	96.1	82.7	75.3	73.8	71.7	78.1
10	97.4	84.9	78.4	77.4	75.5	81
15	94.1	86.6	79.9	78.7	75.9	82.5
20	92.7	86.2	80.2	78.9	78.4	82.1
25	92.6	86.2	80.8	79	78.4	80.3
30	92.5	86.4	81.7	78.9	78.3	82.7
35	92.6	86.1	81.4	79.3	78.5	82.6
40	92.4	86.6	81.8	79.4	79	82.7
45	92.3	86.2	80.9	78.6	78.1	81

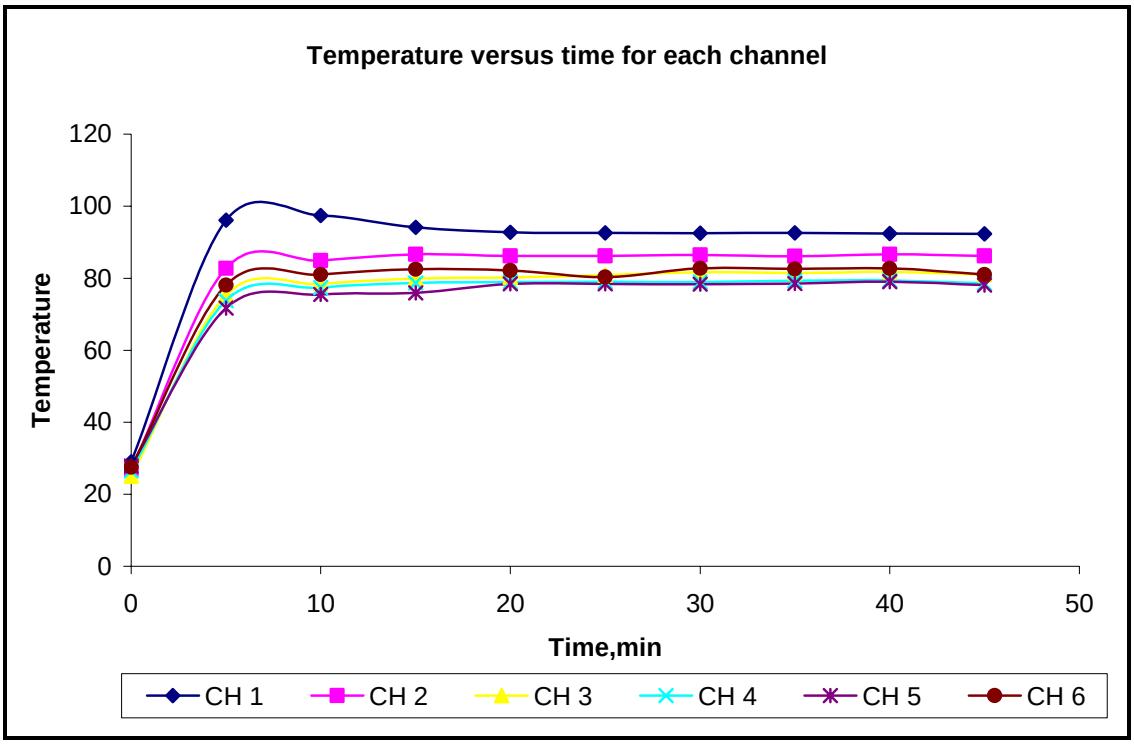

Figure A2: Temperature versus time for each channel

Table A3: Sterilization +PTP 20 min (100°C)+Steam Curtain

Time	CH1	CH2	CH3	CH4	CH5	CH6
0	99	99	99.1	103.5	99.2	99.1
5	99.1	99.1	99.3	103.6	99.4	99.4
10	99.3	99.4	99.6	103.6	99.6	99.5
15	99.5	99.4	99.6	103.8	99.7	99.6
20	99.6	99.7	99.9	103.8	99.8	99.7
25	99.7	99.8	100.1	103.9	100	99.7
30	99.7	99.9	100.2	103.9	100.2	99.8
35	99.7	99.8	100	103.8	99.9	99.7
40	99.8	100	100.1	103.8	99.9	99.8
45	99.9	99.9	100.2	103.9	100.1	99.8

Steam flowrate: 0.96 L/min

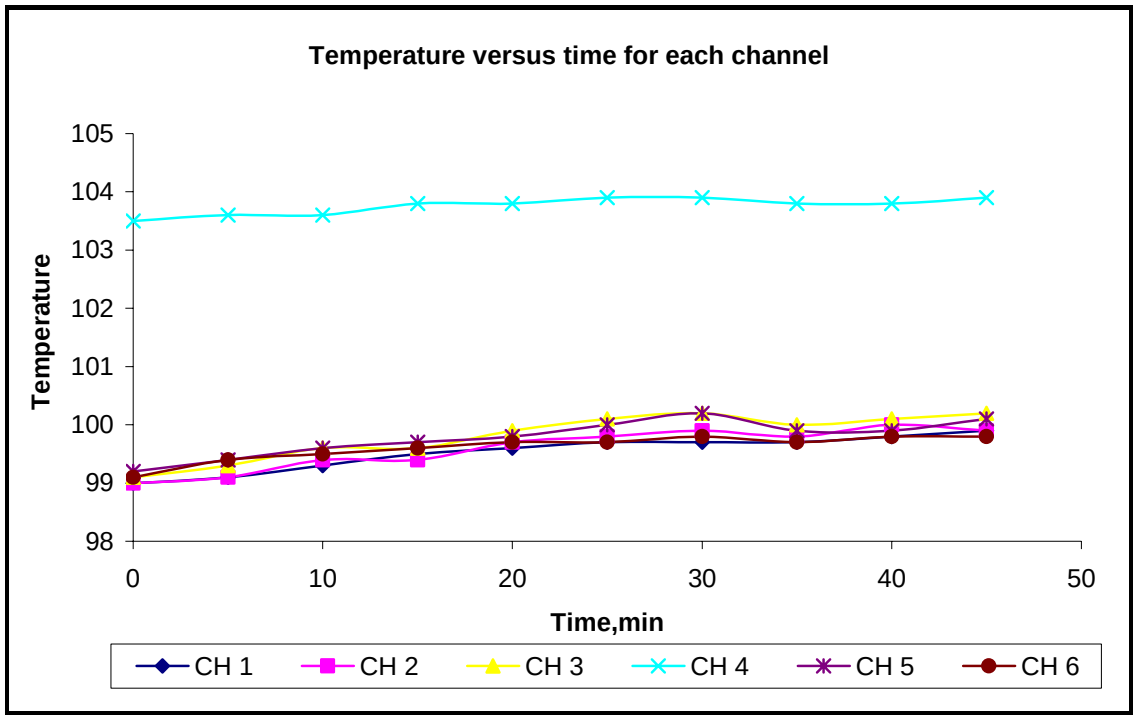

Figure A3: Temperature versus time for each channel

Table A4: Sterilization +PTP 20 min (100°C)+Hot Air Curtain

Time	CH1	CH2	CH3	CH4	CH5	CH6
0	31.7	28.8	26.4	29.4	29.4	31.5
5	98.8	85	70.4	68.1	65.8	69.4
10	99.2	86.7	75.8	74.6	72.5	76.7
15	99.2	87	76.2	75.2	73	77.5
20	99.3	86.5	76.2	75.1	73.1	76.8
25	99.5	87.3	76.5	75.3	73.7	69.6
30	99.4	87.7	77.4	76.5	74.7	78
35	99.5	81.8	77.5	76.5	75	78.5
40	99.5	87.5	77.8	76.6	74.6	78.6
45	99.5	87.7	77.9	76.6	75	78.2

Steam flowrate: 0.96 L/min

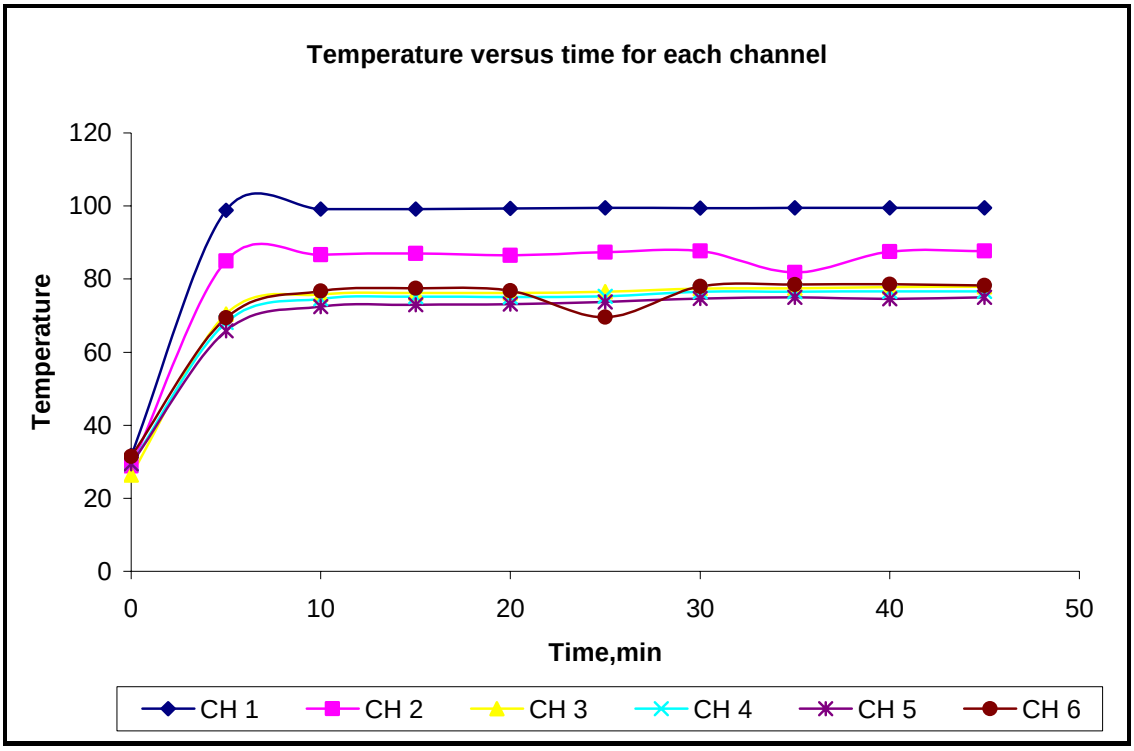

Figure A4: Temperature versus time for each channel

Experiment Bukit Kerayong

The data from Bukit Kerayong as a standard reference .To determine the comparison between the data from mill and lab scale with various methods.

Table A5: Data from Bukit Kerayong Mill

CH 1	CH 2	CH 3	CH 4	CH 5	CH 6	TIME
90.3	90.5	83.1	73.1	68.5	90	2
95.9	96.3	95	89.5	89.1	96	4
98.2	98.2	97.5	93.5	94.4	98	6
98.6	98.7	98.6	94	94.6	98.4	8
98.7	98.6	98.4	94.9	95.2	98.2	10
99.1	99	98.8	95.9	95.5	98.6	12
99.2	99	98.8	94.8	94.8	98.6	14
99.5	99.6	99.3	95.6	96.2	98.8	16
99.5	99.4	99.1	95.8	95.9	98.7	18
99.4	99.3	98.8	97.2	97.4	98.8	20
99.4	99.3	98.6	97.4	97.7	98.1	22
99.5	99.3	98.6	97.6	97.8	98.6	24
99.4	99.3	98.7	97.9	98.1	98.6	26
99.5	99.3	98.7	98	98.1	98.2	28
99.4	99.2	98.6	97.8	97.8	97.1	30
99.2	99	98.3	97.6	97.8	97.9	32
99.2	99.1	98.4	97.3	97.4	98.8	34
99.2	98.9	98.1	97	96.8	98.4	36
99.1	98.7	97.7	96.2	96.2	98.2	38
99.1	98.8	97.9	96.7	96.6	98.6	40
99.2	98.3	98.1	96.8	96.9	98.4	42
99.1	99	97.9	96.6	96.6	98.7	44
99.1	99.2	98.1	96.6	96.7	98.5	46

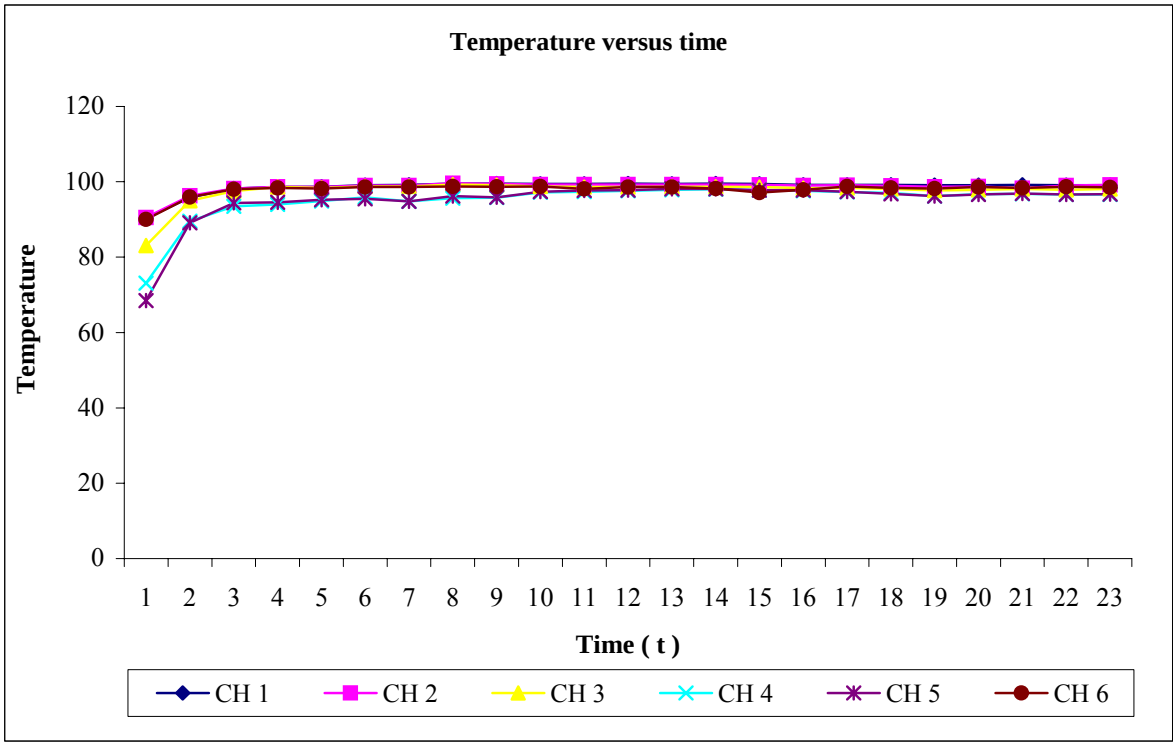

Figure A5: Temperature versus time from Bukit Kerayong mill

Table A6: The data temperature have been taken from each experiment at all the probe location.

CH	Temp 1	Temp 2	Temp 3	Temp 4
1	98.9	77.43	99.53	98.74
2	98.07	79.89	99.6	83.53
3	97.82	74.54	99.81	71.75
4	97.01	73.05	103.76	70.63
5	96.89	72.17	99.78	68.92
6	98.56	76.05	99.61	64.72

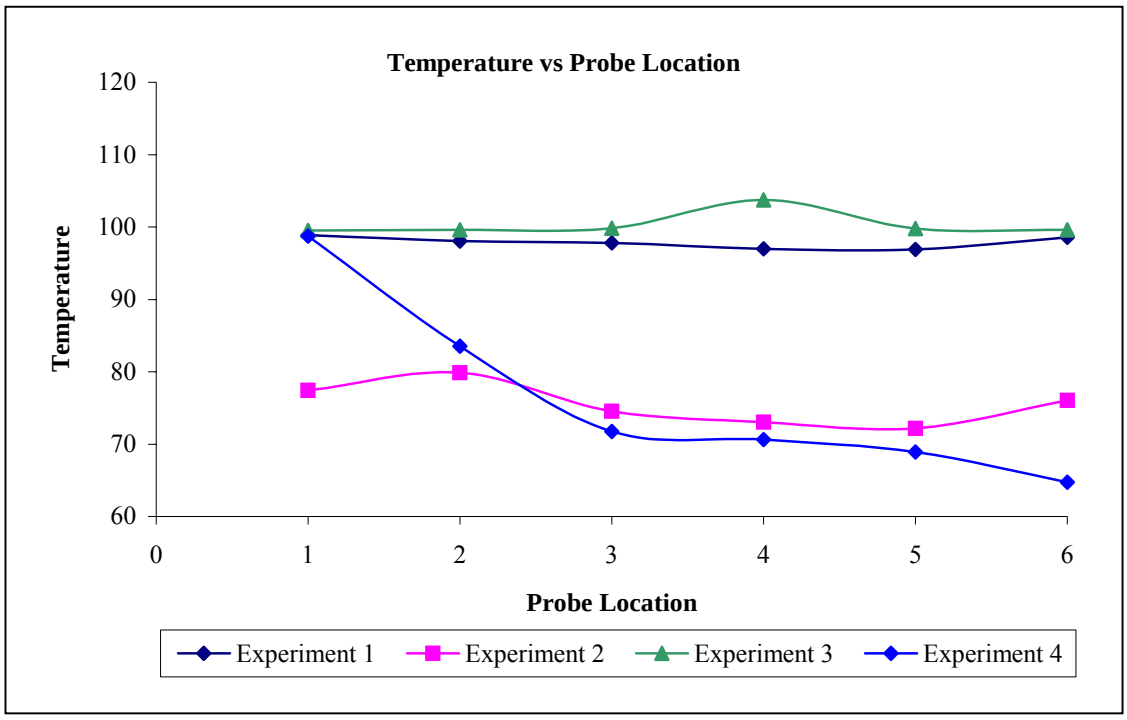

Figure A6: Temperature versus probe location for each experiment

End of Project Report

A. Project number : 72279

Project title : The Study Of Heat Penetration In Palm Oil Fruitlets By Developing A New Technique For Measuring Oil Content In Fruiltlet During Sterilization Process

Project leader: ASSOC. PROF. MUSTAFA KAMAL ABD AZIZ

Tel: 03-2615400 **EXT:** 4860 **Fax:** 03-26935466

B. **Summary for the MPKSN Report (**for publication in the Annual MPKSN Report, please summarise the project objectives, significant results achieved, research approach and team strucure)

The intent of this project was to test, design and build an instrument to measure Oil Content In Fruiltlet During Sterilization Process. This device was to test the performance of the prototype continuous steriliser as commissioned by Kumpulan Guthrie Berhad (KGB) in 1995 to CLEAR and successfully completed.

This project yielded a heat transfer mathematical model of the steam penetration and heat transfer in a fruitlet to predict the successful operating conditions and design specification for oil palm oil cell disruption in sterilization.
Next it build an instrument to measure Oil Content In Fruiltlet During Sterilization Process based on capacitance and thermal capacity measurement. This device is integrated in the prototype continuous steriliser to measure the extent and completion of the sterilisation process. It is operated on capacitance measurement of the fruitlet. It is compared with a more accurate measure of sterilisation by specific heat capacity of the fruitlet in a differential scanning calorimeter.

This is an extension of previous work by MINT to measure electrical properties of oil palm bunches (FFB) on a continuous scale. MINT operated on mulched oil palm bunches but was unstable for pilot plant scale use. This sensor was used to measure fresh fruit bunches after harvesting to determine ripeness by measuring oil content. It was also adapted for measuring refined palm oil purity in the mill and refinery and proved robust and stable. It is unstable when the moisture content is too high at above 5 percent. An algorithm is being developed to overcome this impediment.

The project has not diverted from its original purpose and successfully concluded.

C. Objectives achievement

- **Original project objectives** (Please state the specific project objectives as described in Section ll of the Application Form)

1. In order to implement the continuous sterilizer design, a fundamental understanding of heat transfer through a single fruitlet is first required to study the heat penetration in the fruitlet and its impact on fruit oil cell disruption after sterilization.
2. To design in a fluidized bed of continuous sterilizer for modification from batch process.
3. To simulate the continuous sterilizer process by using the computer modeling method.
4. To develop a method to detect oil content in estate and during various stages of processing in palm oil mill
5. To determine the ripeness of the fruits and oil content by using an electronics sensor.

- **Objectives Achieved** (Please state the extent to which the project objectives were achieved)

Four from five objectives were achieved.

- **Objectives not achieved** (Please identify the objectives that were not achieved and give reasons)

The objective to develop a method to detect oil content in estate and during various stages of processing in palm oil mill was not achieved.

D. Technology Transfer/Commercialisation Approach (Please describe the approach planned to transfer/commercialise the results of the project)

KGB has agreed to a comprehensive training and transfer of technology program with UTM. The program were involved the teaching of chemical engineering technology and hands-on application and operational staff. All activities are conducted jointly by UTM and KGB staff with mutually agreed specific target for every activity. In brief, the transfer of technology involved the teaching and training of chemical technologies, joint research in the application of technology and joint management evaluation of the target and all results at all level of the corporation. This sharing of knowledge and more importantly, the experience of applying technology would serve to enhance the creativity, development and transfer of technology from the international process technologies supplies to the local producer the sustainability of this approach depend on the private sector attitude towards training and transfer of technology the mechanism are in place but what lack is the private conviction towards a Learning Organisation Concept.

E. Benefits of the Project (Please identify the actual benefits arising from the project as defined in Section lll of the Application Form. For examples of outputs, organisational outcomes and sectoral/national impacts, please refer to Section lll of the Guidelines for the Application of R&D Funding under IRPA)

- **Outputs of the project and potential beneficiaries** (Please describe as specifically as possible the outputs achieved and provide an assessment of their significance to users)

  New product and new improved process

- **Organisational Outcomes** (Please describe as specifically as possible the organisational benefits arising from the project and provide an assessment of their significance)

1. Three graduated Master students and a technician who experts in palm oil processing are produced.
2. Designing, purchasing, construction and operation of new design of continuous steriliser
3. CLEAR it is always invited for consultancies, meetings, conferences, symposia and seminars, either national or international, and also recognized by UTM, MPOB and KGB as one of the excellent research centers.

- **National Impacts** (If known at this point in time, please describes specifically as possible the potential sectoral/national benefits arising from the project and provide an assessment of their significance)

  1. Domestic Industry linkage with research institution and universities (KGB, PRSS, PORIM and SIRIM)
  2. Improvement in health, safety, environment and energy comsumption and supply.

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F. Assessment of project structure

- **Project Team** (Please provide an assessment of how the project team performed and highlight any significant departures from plan in either structure or actual man-days utilised)

10 personnel involve (a project leader, 2 researchers, 3 research assistants, 3 postgraduate students, a technician) with 87.85 total man-months on project per year.

- **Collaborations** (Please describe the nature of collaborations with other research organisations and/or industry)

Malaysian Palm Oil Board (MPOB) which expertise in palm oil industrial sector, and SADEX which involves in commission of continuous steriliser equipment.

G. Assessment of Research Approach (Please highlight the main steps actually performed and indicate any major departure from the planned approach or any major difficulty encountered)

As planned

H. Assessment of the Project Schedule (Please make any relevant comment regarding the actual duration of the project and highlight any significant variation from plan)

As scheduled

I. Assessment of Project Costs (Please comment on the appropriateness of the original budget and highlight any major departure from the planned budget)

The original budget requested was RM 852,909.50 but the funding was approved about RM 266,000 for 3 years.

J. Additional Project Funding Obtained (In case of involvement of other funding sources, please indicate the source and total funding provided)

K. Other Remarks (Please include any other comment which you feel is relevant for the evaluation of this project)

Date : 15 July 2003 **Signature :**