EVALUATION OF ALTERNATE SEQUENCE AND ECONOMIC ANALYSIS OF HEATING PROCESS IN A FABRICATION INDUSTRY

Thesis submitted in partial fulfilment of the requirements for the award of the degree of

MASTER OF ENGINEERING IN MECHANICAL ENGINEERING

(INDUSTRIAL ENGINEERING)

of BHARATHIAR UNIVERSITY

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By

K. RAJA

(Reg. No. 9837H0008)

Under the Guidance of

Prof. V. GUNARAJ, M.E., MISTE., I.I.W.,

DEPARTMENT OF MECHANICAL ENGINEERING

KUMARAGURU COLLEGE OF TECHNOLOGY

(Affiliated to Bharathiar University)

COIMBATORE - 641 006

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CERTIFICATE

Department of Mechanical Engineering

Certified that this is a bonafide report

of

the thesis work done by

Mr. K. RAJA

(Reg. No. 9837H0008)

at

KUMARAGURU COLLEGE OF TECHNOLOGY

COIMBATORE - 641 006

During the year – 1998 - 99

17/12/99

Guide
Prof. V. GUNARAJ
Mechanical Engineering Dept,
K.C.T., Coimbatore.

Head of the Department
Dr. MOHANA KRISHNAN

Place : Coimbatore - 6

Date :

Submitted for viva - voce examination held at

Kumaraguru College of Technology on 7-1- 2000

Internal Examiner

External Examiner

ANANDHA FABRICATIONS
(CBE) PRIVATE LIMITED

REGD OFFICE :
'ANANDA NILAYAM'
70, BHARATHI PARK ROAD No. 2
S. B. MISSION (POST)
COIMBATORE - 641 011
Ph. No. Resi : 446213, 449675, 455990
E-mail : anandhafab@hotmail.com.

OFFICE & WORKS :
NEAR SANKARA POLYTECHINC
CHINNAVEDAMPATTI (POST)
COIMBATORE - 641 006
Off. : 866334
Fax No. : 0422 - 866034
Grams : 'ANANDAFAB'

Ref. : AFPL/Admn/309/99-2000

Date : 6-12-99.

CERTIFICATE.

This is to certify that Mr.K.RAJA., M.E., (Industrial Engineering) Student of Kumaraguru College of Technology, Coimbatore - 641 006, undertook the project "EVALUATION OF ALTERNATIVE SEQUENCE & ECONOMIC ANALYSIS OF MANUFACTURING PROCESS IN A FABRICATION INDUSTRY" in our Organisation during the period from 01-06-99 to 30-11-99.

The Project was successfully designed and the performance of the same was satisfactory. The Interest and Conduct of the Student were found to be GOOD.

For Anandha Fabrications (CBE) Pvt. Ltd.,

(M. KANDHASWAMI, B.E., M.I.E.)
Managing Director

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K.RAJA

To recognize trends and to anticipate changes taking place in any technology, are part of the art of good management. Underlying process of changes or improvements in business environment involves the optimization of resources and productivity measurement.

In this project effort has been made to arrive at an optimum heating parameters, so as to reduce the heat-treatment cost. The work has been undertaken at M/s. ANANDHA FABRICATIONS PVT LTD., a fabrication industry, engaged in production of fabricated parts for heavy vehicles of BEML & KIRLOSKAR. Actual Heating process, have many problems associated with time like heating temperature, rate of cooling, rate of heating etc. This problems can be rectified if optimum heating process parameters are used.

An attempt has been made to study and construct an optimum model for the heating process, namely annealing & normalising. The variables such as rate of heating, rate of cooling and heating temperature are modified and experiments are conducted as per central composite rotatable design matrix and the responses are recorded.

With the recorded responses and by using the generic formula mathematical model is developed for each responses. The validations of the mathematical model is then carried.

Based on the mathematical models developed, the process parameters have been optimized for annealing and normalising process using MATLAB software. Also the direct and indirect effects of the process variables on the responses are analysed.

CONTENTS

1.1 Introduction About the Company:-

The company was incorporated on August - 1983. The company has been promoted by Sri M. Kandhaswami. B.E., M.I.E., He has been working as Senior Works Manager in M/s. Everest Engineering Works for 16 years (From 1967 - 1983), and this company has been initiated, after the closure of M/s. Everest Engineering Works. The company now is in the Senior approved vendors list of BEML and BHEL group, and is a Pvt. Limited Concern.

Plant Location and Capacity:-

The factory is situated in $2^1/_2$ acres land on the main road of Saravanampatty to Thudiyalur with EB connections of 150 HP and Diesel set with power generation capacity of 63 KVA. The factory has 600 TONNE Capacity of hydraulic press, with oil fired furnace of size 2M x 2M x 2M. Facilities include rolling of 2500 x 25mm thickness plates, pressing to any shape (including Disked Ends) upto 125mm thick, $C0_2$ TIG, MMA Welding, Stress Relieving, Sand Blasting, Phosphating, Spray Painting, Sheering and Bending. 25 MT Capacity gantry with chain block and winch is provided.

Products Manufactured:-

The company is regularly supplying hot formed Wheel Discs (10mm, 20mm & 40mm thick) for BEML'S Motor graders, Mould Board for 605 &

825 Vehicles. Diesel Tanks, hydraulic Tanks, front - axle, rear-axle, middle frame assembly for BEML / Mysore Unit and Hub assembly for BEML / KGF Unit. Regular supplies include DC Motor fabricated bodies from 5 mm to 80 mm thick for M/s. Kirloskar Electric Co., Bangalore Unit and Compressor tank Dished ends for ELGI Compressors - Coimbatore.

List Of Customers:-

1. ACC Machinery Company Ltd., Coimbatore.
2. Bharat Earth Movers Limited / Mysore Kgf & Bangalore Unit.
3. Carborundum Universal Ltd., / Kanjikode & Kochi Units.
4. Crompton Greaves Ltd ; Ahmed Nagar.
5. Elgi Equipments Ltd - Coimbatore
6. Elgi Tyre & Tread Ltd., - Coimbatore.
7. Elgi Electric & Industries Ltd., - Coimbatore.
8. Garuda Exports., - Madras.
9. Jeetstex Engg. Ltd., - Coimbatore.
10. Kirloskar Electric Company Ltd., - Bangalore.
11. Lakshmi Precision Tools Ltd., - Coimbatore.

12. Sharp Tools - Coimbatore,

13. Shanthi Gears Ltd., - Coimbatore,

14. Universal Heat Exchangers Ltd., - Coimbatore.

1.2 Introduction about the Project:-

Any Industry when confronted with problem should progress through an alternating sequence of evaluation and decision. Cardinal steps on which evaluations and decisions are made in the solution of engineering problems are

1. Recognition of need,
2. Formulation of the problem
3. Resolving the problems into concepts, that suggest a solution.
4. Finding elements for the solution
5. Synthesizing the solution
6. Simplifying and optimizing the solution.

Constraints that must be satisfied by the **problems solution** are to be defined, and all significant forms of solutions which satisfy the constraints should be conceived. From the infinite number of such solutions, the ones, which are best under some criteria of goodness are extracted by using optimization principles beneficially.

Optimizations principles can be beneficially applied to.

1. Problems which involve the operations.

2. Design of system.

Optimization Principles in this project are applied to Problems which involves the operation.

Given a specific measure of performance and a specific set of constraints, we can designate a system as optimum, if it "performs" as well as, if not, better than, any other system which satisfies the constraints.

The term performance measure is used to denote, which is to be maximized (or) minimized. If performance measure and system constraints are clearly evident from the nature of a given problem, system to be optimum is objective. Performance measure is not necessarily a single entity, such as cost, but may represent a weighted sum of various factors of interest (eg) cost, reliability, safety, economy of operations and repair, accuracy of operation, user comfort etc.

In this project, heating process is selected, the constraints identified, and fixing the time, hardness and manufacturing cost as performance measures, the system, is optimized using MATLAB SOFTWARE.

In recent days, every industry, faces tough competition in selling their products. Each and every product being better quality, the one which has competitive (low) price, wins the market.

The company chosen is involved in fabrication work. The material used is constructional mild steel containing 0.2% to 0.3% of carbon. After fabrication, the parts are heat treated. The company at present faces tough competition in selling their fabricated products.

The aim of this project is to arrive at an alternative sequence of working process, with an objective to the reduce the manufacturing time, thereby reducing manufacturing cost of the fabricated products.

Problem Identification :

The regular supplies of the company are fabricated motor bodies, and compressor dished ends. These products after fabricated are heat treated.

The total manufacturing cost of a fabricated motor body is Rs. 4800/-.

Heat treatment cost is Rs. 600/- Ratio of heat treatment cost to manufacturing cost is 1:8.

The total manufacturing cost includes, material cost, labour cost and heat treatment cost. Material cost is subjected to market price fluctuations. Labour cost can be controlled by alloting the work to sub contractors. Therefore, heat treatment process is selected for optimisation.

2.1 Problem Definition :

The material used for fabrication is constructional mild steel containing 0.2% to 03% of carbon. As the carbon content is raised above 0.2%, the strength increases into the range required for constructional purposes, but the ductility decreases. The fabrication qualities of this materials are very good. The steel is often used is hot rolled condition, but the smaller sized material are normalised (or) process annealed.

Therefore 80% of the heat treatment process, is the company is

1. Annealing

2. Normalising

The product selected for annealing process is fabricated motor body. The product selected for normalising is compressor dished ends.

Present Heating Process

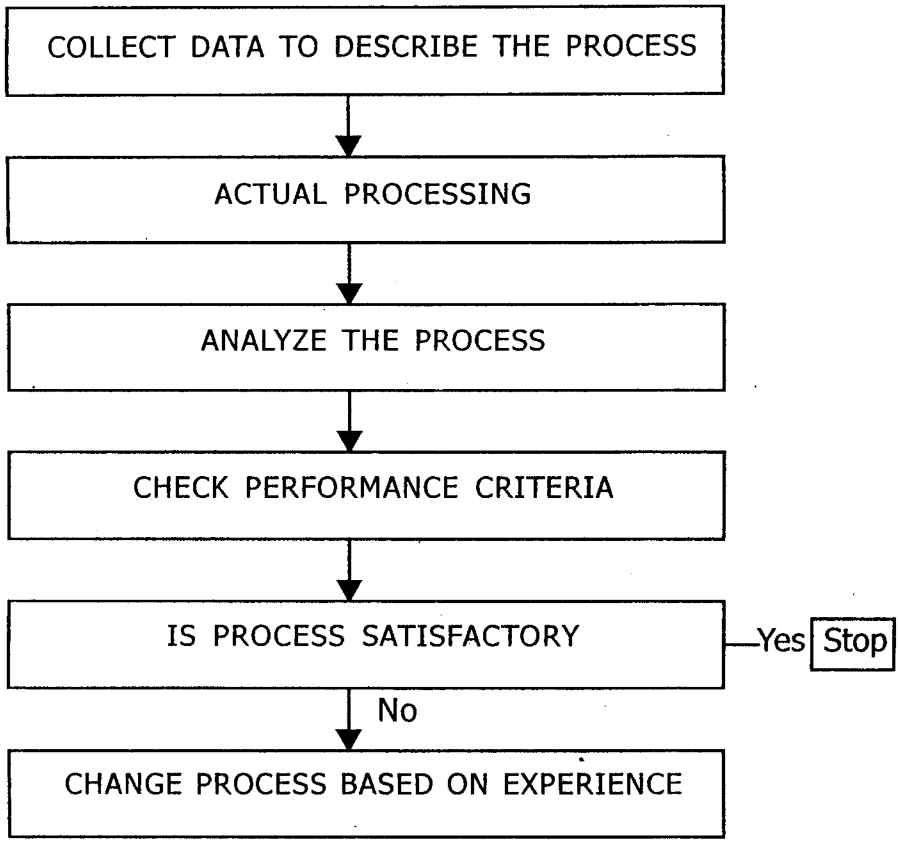


Fig - Process Chart - 1

So, it is evident that the process variables are fixed based on experience. This may not be the optimum value. This is the problem that the author has identified and so, in this project, effort has been put forth to derive at are optimum process variables, so that the manufacturing time and thereby manufacturing cost is reduced.

The first phase of any research work is to survey the available or existing literature relevant to the selected topic in order to avoid duplication of work and to study what is not investigated in that area of the subject. This aspect of study not only helps to avoid wastage of time, energy and material in carrying out the basic work by starting from the scratch match, but also helps one to concentrate on advanced research work from a fairly high level because the already existing (or) established procedures can be easily adopted for studying (or) developing never things. It was, therefore decided to carry out the survey of available literature to gain the maximum advantage out of it. A brief and selective review of the relevant available information collected is presented under the following headings.

3.1. Principles of heat Treatment

3.2. Experimental Techniques

3.3. Design of experiments

3.1 Principles of Heat treatment

Heat treatment is an operation, (or) combination of operations, involving the heating and cooling of a material in the solid state, for the purpose of obtaining certain desirable properties.

Heat Treatment Cycle Consist of 3 Main Stages.

(a) Heating at a suitable rate.

(b) Holding at an appropriate temperature for the required time.

(c) Cooling at an appropriate time.

According to B. Venkateswaran of M/s. Promot Industrial consultancy service [23], it is usually desirable for the heating rate to be quite rapid, but if it is too fast, then in equalities of expansion in the material may lead to distortion or even cracking of the work piece. Also the soaking temperature is important because it determines the type of structure which will be produced and the rate at which structural changes will proceed, [23]. The soaking time is important because, it determines the extent to which structural changes progress towards completion and the attainment of equilibrium. Control of the cooling rate is required because of its effect on the final structure. A very slow cooling rate may be essential to achieve a state of complete equilibrium.

Also M/s. Promet Industrial Consultancy Services states that [23] Process Control is very important and is exercised through the paramaters a. Tempearture, b. Time, c. Furnace Atmosphere.

Annealing :

Process Annealing of cold-worked low-carbon steels (Less than 0.3% of carbon) :

According to M/s. Promet Industrial consultancy services, this process involves the recrystallisation of ferrite as a result of heating after cold working. Cold worked low carbon steels are heated in an atmosphere to 600^{0}c (ie) to below the lower critical temperature, so that the process is also known as "subcritical annealing". This treatment will not affect the pearlite, so that after process annealing, the pearlite remain longated in the direction of cold working.

Normalising :

M/s. Promet Industrial consultancy services states that [32] Normalising is carried out on low and medium carbon steels. The process is applied to achieve the best combination of mechanical properties when it is undesirable for the material to be in the safest possible conditions ((ie) fully annealed). The treatment involves, heating the steel to about 30^{0} c above its upper critical temperature ((ie) the same temp as per full annealing) but followed by cooling in still air. The more rapid cooling produces finer ferrite and smaller grain size, resulting in a slightly harder and stronger material. However, the properties actually obtained in a normalised steel will very will the section thickness.

3.2 Experimental Technique

In recent years, research workers have turned increasingly to statisticians for help both in planning their experiments and in drawing conclusions from the results. It is a common characteristic of experiments in widely diverse fields of research that, when they are repeated, the effects of the experimental treatments very from tiral to trial. This variation introduces a degree of uncertainty into any conclusions that are drawn from the results. Successive trials may be so discrepant in their results that it is doubtful which of two treatments would turn out better in the long run.

According to Cochran and Cox (4), the statistical solution to the problem of estimation consists of a statement that the true difference lies between certains limits, plus a probability that the statement is correct. Further it is stated that, if it is important to make the correct decision, further experiments must be conducted in order to narrow the distance between the confidence limits. Cochran and Cox (4) states that the contribution of statistics is the operation known as test of significance.

Cochran and Cox (5) states that, tests of significance are less frequently useful in experimental work than confidence limits. The real problem is to obtain estimates of the sizes of the differences.

Variability in results is typical in many branches of experimentation. Because of this, the problem of drawing conclusions from the results is a problem in induction from the sample to the population. The statistical theories of estimation and of testing hypotheses provide solutions to this problem in the form of definite statements that have a known and controllable probability of being correct. These statements are specific enough to be useful is deciding whether action can be taken are the basis of the results.

According to Cochran and Cox [7] randomization is one of the few characteristics of modern experimental design that appears to be really modern. Of-course, in experiments where a great number of physical operations are involved, the application of randomization to every operation becomes time consuming, and the experimenter may use his judgement in omitting randomization where there is a real knowledge that the results will not be vitiated. It should be realized, however, that failure to randomize at any stage may introduce bias unless either the variation introduced in that stage is negligible (or) the experiment effectively randomizes itself.

The features of experiment (14) that should be included in the draft of the proposals are the number of replications, the types of experimental material to be used, and the measurements that are to be made.

3.3. Design of experiments:-

The most informative method of analysis of the results of a factorial experiment depends on the nature of the factors. If all the factors represent quantitative variables like time, temperature, it is natural to think of the yield (or) response y as a function of the levels of these variables. According to Box [8 A.1], it is written as

$$y_u = \varphi (X_{iu}, (X_{zu}, \ldots\ldots\ldots X_{ku}) + e_u$$

Where u = 1,2,...... N represents the N observations in the factorial experiment and x_{1u} represents the level of the ith factor in the uth observation. The function φ is called the response surface. The residual e_u measures the experimental error of the uth observation. A knowledge of the function φ gives a complete summary of the results of the experiment and also enables us to predict the response for values of the X_{iu} that were not tested in the experiment.

Some experimental designs and method of analysis have been developed for fitting polynomials of the first and second degree. Box [8 A-1] has called these designs first order designs and second order designs respectively.

Second Order Design :

The general form of a quadratic polynomial is illustrated by the equations for two X-variables.

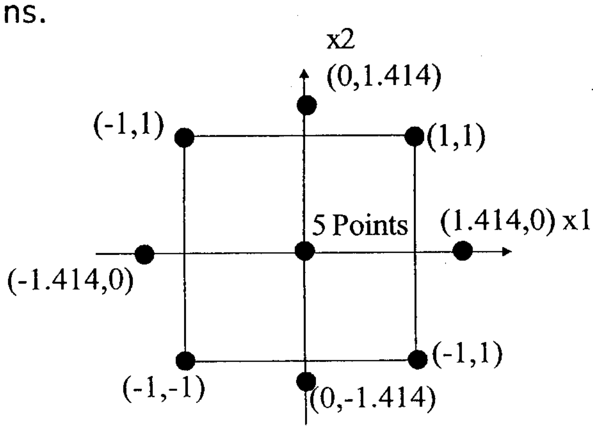
$$Y_u = B_o + B_1 X_{lu} + B_2 X_{2u} + B_{11} X_1 U^2 + B_{22} X_2 U^2 + B_{12} X_{1u} X_{2u} + e_u$$

The surface contains linear terms in X_{1u}, X_{2u}, squared terms in X_{1u}^2, X_{2u}^2, and the cross product term $X_{1u} X_{2u}$.

According to Box [8 A 21] in order to estimate the regression co-efficients in this model, each variables X_{lu} must take at least three different levels. This suggests the the use of factorial design of the 3^K series. If the three levels of any X are coded as -1, 0, 1, the second order surface is easy to fit to the results of a 3^K factorial

Rotatable Second order Design:

In a more intensive consideration of desirable properties, Box and Hunter [8A.7] proposed the criterion of rotatability. The rotatable designs most likely to be useful in proctice belong to a series that are also central composite designs.



As stated by Box [8A.23], the design may be sub divided into three parts.

(i) The four points (-1, -1), (1, -1), (-1,1) and (1,1) constitute a 2^2 factorial.

(ii) The four points $(-\sqrt{2},0)$, $(\sqrt{2},0)$ $(0,-\sqrt{2})$, $(0.\sqrt{2})$ are the exta points included to form a central composite design with $a = \sqrt{2}$.

(iii) Five points are added at the center to give roughly equal precision for y within a circle of radius 1.

The regression co-efficients are computed directly by the equations given below, as per table [8A.7]

$$b_0 = 0.2\,(oy) - 0.1 \sum (iiy) \quad \text{where} \sum (iiy) = (11y) + (22y)$$

$$bi = 0.125\,(iy)$$

$$bii = 0.125\,(iiy) + 0.1875 \sum (iiy) - 0.1\,(oy)$$

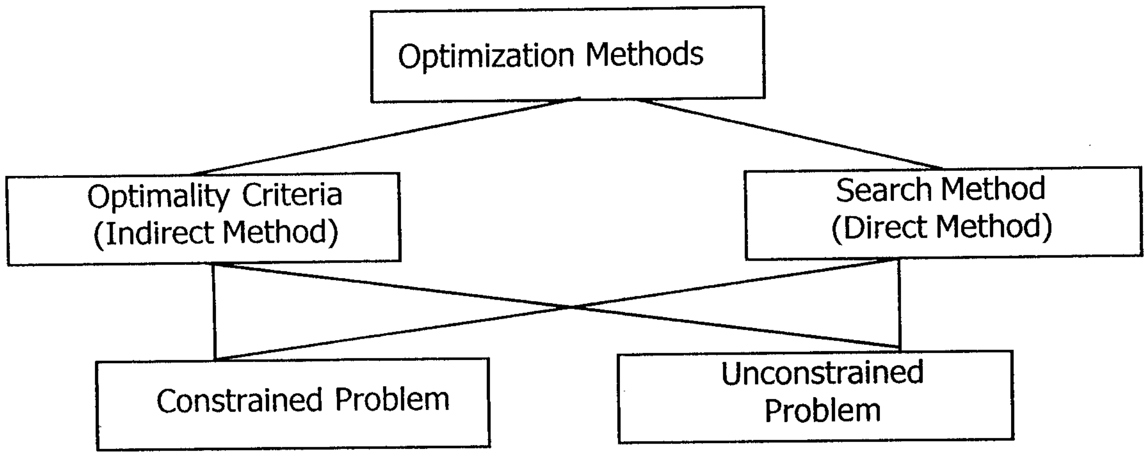
$$bij = 0.25\,(ijy)$$

Optimization Techniques:

As stated by Cox [3.1], it is realized that the overall process of designing systems in different fields of engineering is regularly the same. Analytical and numerical methods for analysing various systems can differ somewhat. Statement of the design problem can contain terminology that is specific to the particular domain of application. However, once the problems from different fields have been transcribed into mathematical statements using a standard notation, they all look alike.

Two categories of optimization techniques are 1. Indirect (or) Optimallity criteria method and 2. Direct (or) search methods. Optimality criteria are the conditions a function must satisfy at its minimum point. Minimization techniques seeking solutions to optimality conditions are after called indirect methods.

The direct techniques are based on a different philosophy. There we start with an estimate of the optimum design for the problem. Usually the starting designs will not satisfy optimality criteria. Therefore, it is improved iteratively until they are satisfied. Both categories have constrained and unconstrained problems.



Fundamental Concepts: To discuss optimal design concepts, we need basic ideas from vector and matrix Algebra, and vector calculus. The idea of Taylor series expansion is fundamental to the development of optimal design concepts and numerical methods. The concept of quadartic forms is needed to develop sufficiency condition for optimality.

Unconstrained Optimum Design Problems: Here we consider the problem of minimizing a function with no constraints or design variables.

Constrained optimum Design Problems: Here, the necessary conditions for a equality constrained problem are discussed. These conditions are contained in the Lagrange Multiplier Theoram generally discussed in test books on calculus. The necessary conditions for the general constrained problem are obtained as an extension of the Language Multiplier Theorem.

Global Optimality: For a class of problems, known as the convex programming problems, it is possible to determine the global optimum solution. To study them, we need the concepts of convex functions.

Second Order Conditions for Constrained Optimization : Here second order necessary and sufficiency conditions are studied. They require calculation of Hessians of cost and constraint functions.

Post optimality Analysis: Physical meaning of Lagrange Multipliers. The physical interpretation allows a designer to study the effect of loosening (or) tightening constraints of the design problem. The Lagrange Multipliers at optimum point provide the necessary information to study this effect.

Explanation of Problem Solving :

OPTIMUM HEATING PROCESS

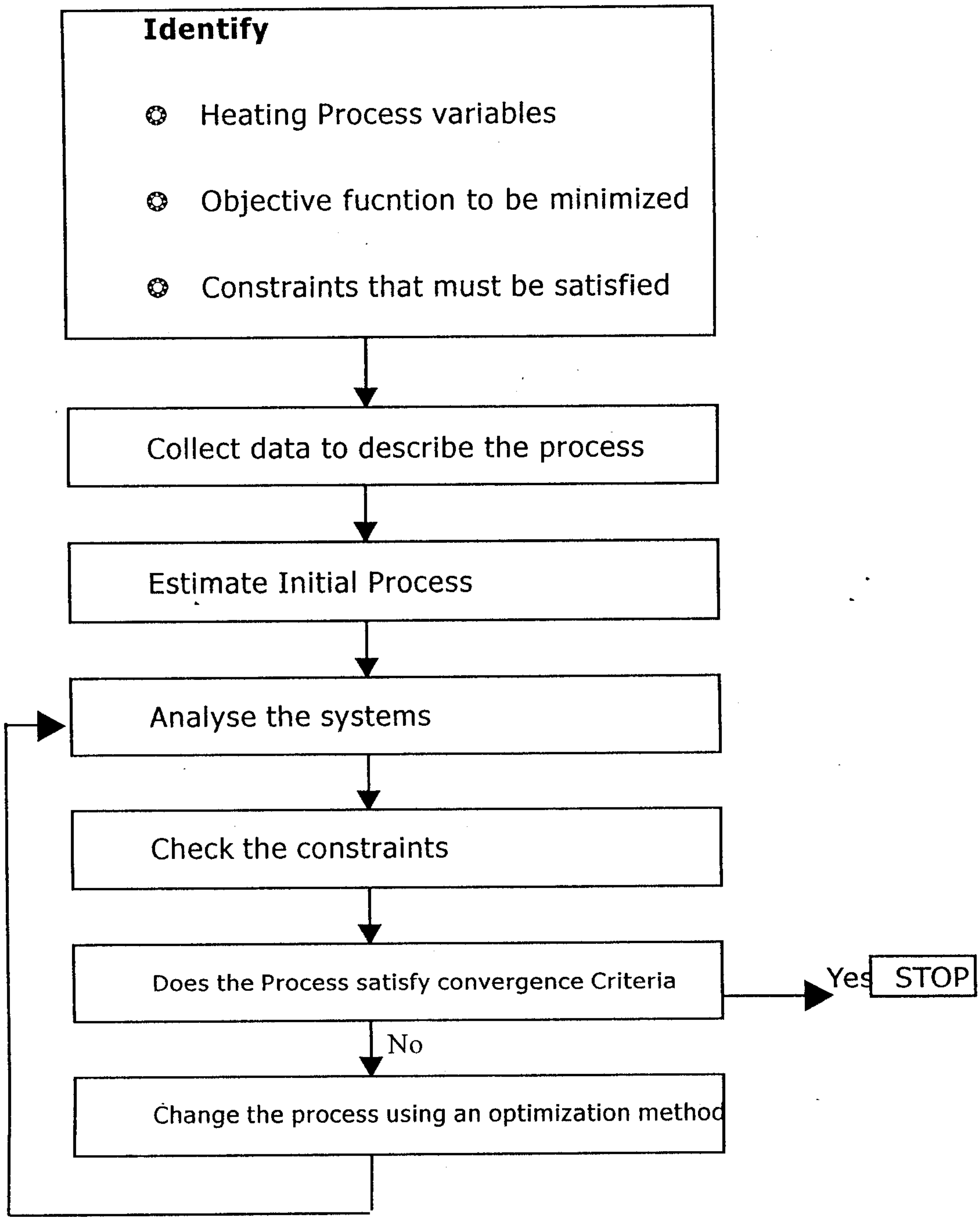


Fig - Process Chart - 2

The optimum design process forces the designer to identify explicitly a set of design variables cost functions to be minimized, and the constraint functions for the system.

Proper mathematical formulations of the design problem is a key to good solutions. The optimum design process is iterative, requiring the use of the same set of calculations repeatedly. It can be seen that the amount of data generated in the iterative process can be enourmous, which must be presented in a comprehensible form. Graphical representation of data is well suited for this purpose. The optimal control problem is to find feedback controllers for a system to produce the desired output.

Means for Higher Productivity :

It should be remembered that increased productivity is not solely achieved by worker's effort. Generally increased productivity can be achieved through simplification and standardisation of the working process.

Improved methods of simplifications are, better planning and scheduling to minimize the bottle necks, down time, better material handling system, better workplace layout, improved working condition etc.

In this project, focus is made to obtain optimum heating parameters, thereby reducing the heating time and the heat-treatment cost, thus increasing the productivity.

Decision Variables :

In an engineering task, the numerical quantities for which values are to be closer will be called decision variables (or) more shortly variables. In mathematical programming, these quantities are denoted as Xi, where i = 1,2,3.....n. Thus Xi is a variable representing the i^{th} quantity.

Decision Variables and Parameters :

In some optimization models, the choice of the number and type of decision variables is simple but quite often the situation is not very clear.

At the stage of building the optimization model, we have to decide which quantities are treated as decision variables and which are taken as fixed. The quantities whose values are fixed are called as parameters. Mathematical relations between the decision variables and the parameters constitute engineering optimization model.

Quantities may be designated as parameters for various reasons. A common one is that, we are simply not at liberty to change that particular quantity. In some cases, it may be known from experience that a particular value (or) the quantity always gives good results, hence, there is no reasons to treat this quantity as decision variable. Some times, at the beginning of building the optimization model, it is difficult to decide which quantities are to be treated as the parameter and which as decision variables.

Generally, we are free to choose the values of any quantity, then this quantity should be treated as parameters, even if it could be considered as decision variables. Thus the optimization model is easier to solve.

Constraints :

In each engineering task, there are some restriction dictated by environment, in order to produce an acceptable solution. These restrictions are collectively called constraint functions and describe dependences among decision variable and parameters. These dependences are written in the form of mathematical inequalities and sometimes also equalities.

Objective Functions :

In the process of selecting a "good solution" from all solution which satisfy the constraints, there must be some criteria, which allow these solutions to be compared. These criteria are the inherent qualities of each solution and in the inherent qualities of each solution and in the optimization model, they must be expressed as computable functions of the decision variables. These function called the objective functions, are apparently non-commensurable and usually some of them will be in conflict with others. We designate the objective functions as f_1, f_2.........f_K emphasing their dependence upon the decision variables as $f_1(x)$,. $f_2(x)$............

Methodology is explained in the following steps :

1. Selecting the components which are critical.
2. Selecting the process which is complicated in that component.
3. Finding the process variables for the process.
4. Finding the working zone for each and every process.
5. Setting the limit values, using the working zone for doing the experiment.
6. Conducting the experiment as per central composite rotatable design.
7. Recording the responses for each and every iterative process in the experiment.
8. Forming the equations by formula calculations.
9. With the developed equation, the optimum value for the process is found using MATLAB software.
10. Validation of the mathematical model is carriedout.
11. Analysing the result by means of graphical representation.

5.1 Selecting the component :

The regular supplies of the company are listed, and from this, the products, which are facing tough competition are sorted out. Two such products are

a. Fabricated motor body
b. Compressor tank dished ends.

Selecting the critical process :

As identified earlier, heating process is selected for optimizations. 80% of heat treatment process in the company is Annealing and Normalising. Thus the two process are selected for optimisation.

Finding the variables for the process :

The variables in the heating process are identified and are as follows

b. Rate of heating.

c. Heating Temperature

d. Rate of cooling.

5.2 Finding the working zone :

The variables, will have a minimum and maximum limit within which, the desired output would be achieved. This limit is termed as working Zone. This can be found by trial and error method. By keeping two variables fixed, and varying the other variables and by recording the result, the minimum and maximum limit of that variables can be found. Similarly, the working zone of other variables are fixed.

Setting the limit values :

For conducting the experiment, values are assigned according to Central Composite rotatable design. The maximum limit, minimum limit and Normal limit are assigned with experimental values as shown in the table.

5.3 Conducting the experiment :

As per the design matrix (shown in the table) of the central composite rotatable design, experiment is conducted. Since there are two variables in each process, the number of trials conducted is 13.

5.4 Recording the responses :

As per the experiment conducted, (13 trails of varying limits of variables) the responses are recorded for each trial. Responses are manufacturing cost, heating time and Hardness. So 13, such values for each responses are recorded.

5.5 Forming the equations :

For second order, two variable process, the general formula is

$$y = b_0 + b_1X_1 + b_2X_2 + b_{11}X_1^2 + b_{22}X_2^2 + b_1b_2X_1X_2$$

Where b_0, b_1..... are co-efficients and X_1X_2 are variables.

Thus a mathematical model is developed.

5.6 Finding the optimum values :

From the mathematical equations (3 in case of three responses) developed, the objective function is choosen and the constraints are decided. By using MATLAB software, optimum value of the objective function is found.

5.7 Validation of the Mathematical model :

Validation is carriedout by plotting a scatter diagram for the observed values and predicted values of each response. Also by using SYSTAT software validation is carriedout.

5.8 Analysing the results :

The direct and indirect effect of the process variables, rate of beating, rate of cooling, and heating temperature on the responses, cost, time and hardness are graphically analysed.

Design Matrix :

Table - A

x_0	x_1	x_2	x_1^2	x_2^2	x_1x_2
1	-1	-1	1	1	1
1	1	-1	1	1	-1
1	-1	1	1	1	-1
1	1	1	1	1	1
1	-1.414	0	2	0	0
1	1.414	0	2	0	0
1	0	-1.414	0	2	0
1	0	1.414	0	2	0
1	0	0	0	0	0
1	0	0	0	0	0
1	0	0	0	0	0
1	0	0	0	0	0
1	0	0	0	0	0

Working Zone

Table - 2

S. No.	Process Variables	Limits (^0C / hv)		
		Minimum	Normal	Maximum
1.	Rate of Heating	100	150	200
2.	Rate of Cooling	50	75	100

PROCESS VARIABLES AND THEIR LIMITS

Table - 3

S. No.	Variables (^0C/hv)	Symbol	Limits		
			-1	0	1
1.	Rate of Heating	H	100	150	200
2.	Rate of Cooling	C	50	75	100

6.1 Development of Mathematical Model for Responses of Annealing Process :

Response y_1 = cost (Rs.)

S. No.	R_HY_1	R_CY_1	$R_HY_1^2$	$R_CY_1^2$	$R_HR_CY_1$	Response Y_1
1.	-1500	-1500	1500	1500	1500	1500
2.	1100	-1100	1100	1100	-1100	1100
3.	-1300	1300	1300	1300	-1300	1300
4.	900	900	900	900	900	900
5.	-1908.9	0	2700	0	0	1350
6.	1343.3	0	1900	0	0	950
7.	0	-1838.2	0	2598.7	0	1300
8.	0	1555.4	0	2598.7	0	1300
9.	0	0	0	0	0	1150
10.	0	0	0	0	0	1150
11.	0	0	0	0	0	1150
12.	0	0	0	0	0	1150
13.	0	0	0	0	0	1150
Total	-1365.6	-682.8	9398.23	9597.6	0	15250

Table - 4

Response y_2 = hardness (HRC)

S. No.	R_HY_2	R_CY_2	$R_HY_2^2$	$R_CY_2^2$	$R_HR_CY_2$	Response Y_2
1.	-98	-98	98	98	98	98
2.	99	-99	99	99	-99	99
3.	-99	99	99	99	-99	99
4.	97	97	97	97	97	97
5.	-138.572	0	195.902	0	0	98
6.	138.572	0	195.902	0	0	98
7.	0	-138.172	0	193.902	0	97
8.	0	137.158	0	193.903	0	97
9.	0	0	0	0	0	97
10.	0	0	0	0	0	99
11.	0	0	0	0	0	99
12.	0	0	0	0	0	99
13.	0	0	0	0	0	98
Total	-1	-2.414	784.804	82.805	-3	1274

Table - 5

Response y_3 = heating time (Hours)

S. No.	Y_3	R_HY_3	R_CY_3	$R_H^2Y_3$	$R_C^2Y_3$	$R_HR_CY_3$
1.	12	-12	-12	12	12	12
2.	10	10	-10	10	10	-10
3.	8	-8	8	8	8	-8
4.	6	6	6	6	6	6
5.	9.15	-12.93	0	18.3	0	0
6.	7.15	10.1101	0	14.3	0	0
7.	10.45	0	-14.77	0	20.9	0
8.	6.45	0	9.12	0	12.9	0
9.	8	0	0	0	0	0
10.	8	0	0	0	0	0
11.	8	0	0	0	0	0
12.	8	0	0	0	0	0
13.	8	0	0	0	0	0
Total	110	-6.82	-13.65	68.6	99.8	0

Table - 6

General formula for developing a mathematical model, for second order, two variable process are

$Y = b_0 + b_1X_1 + b_1X_1 + b_2X_2 + b_{11}X^2_1 + b_{22}X^2_2 + b_{12}X_1X_2$

where b_0, b_1........ are regression coefficients and X_1, X_2 are variable. Y is the response.

ANNEALING PROCESS :

Development of mathematical model for heat-treatment cost

$b_0 = 0.2\ (0y_1) = 0.1\ iiy = 1150.4$

$b_1 = 0.125\ (iy) = -1707$

$b_2 = 0.125\ (jy) = -85.35$

$b_{11} = 0.125\ (iiy) + 0.1875\ (iiy) - 0.1\ (0Y) = 1502.35$

$b_{22} = 0.125\ (jjy) + 0.01875\ (iiy) - 0.1\ (0y) = 1527.278$

$b_{12} = 0.25\ (ijy) = 0$

Heat treatment Cost $= 1150.4 - 170.7X_1 - 85.35X_2 + 1503X_1^2 + 1528X^2_2$

Where X_1 = Rate of heating

and X_2 = Rate of Cooling

Development of mathematical model for hardness

$b_0 = 0.2 \ (0y_2) \ = 0.1 \ \Sigma \ (iiy) \ = 98.039$

$b_1 = \ 0.125 \ (iy) \ = -0.125$

$b_2 = 0.125 \ (jy) \ = -0.3017$

$b_{11} \ = 0.125 \ (iiy) \ + 0.1875 \ \Sigma \ (iiy) -0.1 \ (0Y_2) \ = 0.09316$

$b_{22} \ = 0.125 \ (jjy) \ + 0.1875 \ \Sigma \ (iiy) \ -0.1 \ (0Y_2) = 0.1567$

$b_{12} \ = 0.25 \ (ijy) \ = 0.75$

HARDNESS

$$= 98.04 - 0\text{-}13X_1 - 0.30X_2 \ - 0.300 + 0.94X_1^2 \ - 0.16X_2^2 \ - 0.8 \ X_1 \ X_2$$

Development of mathematical model for heating time

$b_0 = 0.2 \ (0y_3) \ = 0.1 \ \Sigma \ iiy \ = 5.16$

$b_1 = \ 0.125 \ (-6.82) \ = -0.8525$

$b_2 = 0.125 \ (-13.65) \ = -1.706$

$b_{11} \ = 0.125 \ (iiy) \ + 0.1875 \ \Sigma \ iiy -0.1 \ (0Y) \ = 0.7325$

$b_{22} \ = 4.6325$

$b_{12} \ = 0$

Heating Time $= \ 5.16 \ - \ 0.85 \ X_1 \ - \ 1.70 \ X_2 \ + \ 0.73 \ X_1^2 \ + \ 4.63 \ X_2^2$

6.2 Development of Mathematical Model for Responses of Normalising Process :

Response y_1 = cost (Rs.)

S. No.	Y_1	R_HY_1	T_1Y_1	$R_H^2Y_1$	T^2Y_1	R_HTY_1
1.	1700	-1700	-1700	1700	1700	1700
2.	750	750	-750	750	750	-750
3.	1750	-1750	1750	1750	1750	-1750
4.	800	800	800	800	800	800
5.	1750	-2474.5	0	3500	0	0
6.	750	1060.5	0	1500	0	0
7.	900	0	-1272.6	0	1800	0
8.	1000	0	1414	0	2000	0
9.	950	0	0	0	0	0
10.	950	0	0	0	0	0
11.	950	0	0	0	0	0
12.	950	0	0	0	0	0
13.	950	0	0	0	0	0
Total	14150	-3314	241.4	10,000	8,800	0

Table - 7

Response y_2 = hardness (HRC)

S. No.	Y_2	R_HY_2	T_1Y_2	$R_H^2Y_2$	T^2Y_2	R_HTY_2
1.	93	-93	-93	93	93	93
2.	95	95	-95	95	95	-95
3.	95	-95	95	95	95	-95
4.	93	93	93	93	93	93
5.	95	-134.33	0	190	0	0
6.	93	131.502	0	186	0	0
7.	94	0	-132.916	0	188	0
8.	94	0	132.916	0	188	0
9.	94	0	0	0	0	0
10.	94	0	0	0	0	0
11.	94	0	0	0	0	0
12.	94	0	0	0	0	0
13.	94	0	0	0	0	0
Total	1222	-28.28	0	752	752	-4

Table - 8

Response y_3 = Heating time (Hours)

S. No.	Y_3	R_HY_3	T_1Y_3	$R_H^2Y_3$	T^2Y_3	R_HTY_3
1.	6.30	-6.30	6.30	6.30	6.30	6.30
2.	3.15	3.15	-3.15	3.15	3.15	-3.15
3.	7.00	-7.00	7.00	7.00	7.00	-7.00
4.	3.30	3.30	3.30	3.30	3.30	3.30
5.	6.45	-9.1203	0	12.896	0	0
6.	3.30	4.46662	0	6.5980	0	0
7.	4.15	0	-5.8681	0	8.29749	0
8.	4.30	0	6.0802	0	8.89740	0
9.	4.30	0	0	0	0	0
10.	4.30	0	0	0	0	0
11.	4.30	0	0	0	0	0
12.	4.30	0	0	0	0	0
13.	4.30	0	0	0	0	0
Total	61.45	-11.3041	1.0621	39.244	36.64489	-0.55

Table - 9

Normalising Process :

Development of mathematical model for cost

$b_0 = 0.2 \ (0y_1) = 0.1 \ \Sigma \ iiy = 950$

$b_1 = 0.125 \ (iy) = -414.25$

$b_2 = 0.125 \ (jy) = 30.175$

$b_{11} = 0.125 \ (iiy) + 0.1875 \ \Sigma \ iiy - 0.1 \ (0Y) = 187.5$

$b_{22} = 0.125 \ (8800) + 0.01875 \ [(10{,}000 + 8{,}8000] \ -0.1 \ (14150) = 37.5$

$b_{12} = 0.25 \ (ijy) = 0$

$COST = 950 - 414.25 X_1 + 30.175 X_2 + 187.5 X_1^2 + 37.5 X_2^2$

Development of mathematical model for hardness

$b_0 = 0.2 \ (0y_1) = 0.1 \ \Sigma \ iiy = 94$

$b_1 = 0.125 \ (iy) = -3.535$

$b_2 = 0.125 \ (jy) = 0$

$b_{11} = 0.125 \ (iiy) + 0.1875 \ \Sigma \ iiy - 0.1 \ (0Y) = 0$

$b_{22} = 0.125 \ (IJY) + 0.01875 \ 0.01875 \ \Sigma \ (ijy) \ -0.1 \ (oy) = 0$

$b_{12} = 0.25 \ (ijy) = -1$

$HARDNESS = 94 - 3.535 X_1 + X_1 X_2$

Development of mathematical model for heating time

$b_0 = 4.70$

$b_1 = 1.413$

$b_2 = 0.1327$

$b_{11} = 0.1834$

$b_{22} = -0.141$

$b_{12} = 0.1375$

HEATING TIME

$$= 4.7 - 1.4\ X_1 + 0.132\ X_2 + 0.19\ X_1^2 - 0.15\ X^2_2 - 0.14 X_1 * X_2$$

MATLAB SOFTWARE

It is one of the powerful software for the optimization of the process. It is used for numeric computation, visualization and data analysis. It is used for customizing the MATLAB environment with special tools to solve more application's specific problems. Among these are controls, signal processing, neural nets and so on.

MATLAB is are expression language. It interprets and evaluates expressions typed in at the key board. Statements are usually in the form of variables. In this, matrix is also one of the element of MATLAB. The matrix can be any matter expression. Individual matrix elements can be represented with indices inside paranthesis ().

Matlab uses conventional decimal notation, with optimal decimal point and loading minus sign, for numbers. It accepts with equal ease, real, imaginary and complex numbers. It allows complex numbers, indicated by special functions.

Matrix expressions are fundamental to MATLAB. Where ever possible they are indicated the way they are in a text book. For addition and substraction, the array operation and matrix operations are important.

7.1 Procedure For Optimization Using Matlab Software

Annealing process :

Heating Cost = $1150.4 - 170.7\ R_H - 85.35\ Rc + 1503\ R^2{}_H + 1528Rc^2$

Heating Time = $5.16\ - 0.85\ R_H - 1.70\ R_C + 0.73\ R2_H + 4.63\ R2_C$

Hardness = $98.04\ - 0.13\ R_H - 0.30\ R_C + 0.94\ R^2{}_H - 0.16\ R^2{}_C - 0.8R_H.R_C$

Normalising Process :

Heating Cost = $950 - 414.25\ R_H + 30.1757 + 187.5\ R^2{}_H + 37.Rc^2$

Heating Time = $4.7\ - 1.4\ RH\ + 0.132\ T + 0.19\ R2H\ - 0.15T2$

Hardness = $94 - 3.535\ R_H - (1)\ R_HT$

Selection of objective function and constraints :

The objective function selected for optimization is the total heating cost of the heating process. The working zone in which solution for the objective function lies, decrease as the number of constraint increases. Hence important heating process parameters, are given as constraints in their equation form.

In optimization, generally the constraints with their upper limits should be given in such a way that their value will be less than (or) equal to zero. All the objective function and the constraint function will always be minimized usually. The process variables and their notations used in heating process for optimization using MATLAB software are given below.

X (1) = Rate of heating

X (2) = Rate of cooling

Optimization of the objective function:-

The main objective of this study is to minimize the cost of the total heating process, with the their important process parameters within limits limits as constraints. The step by step procedure of minimization cost of total heating process using the optimization model available in the tool box of the Matlab version 4.26 software package is given below. The constrained minimum of a scalar function of several variables of an initial estimate which is referred as constraints non linear optimization and is mathematically stated as

Minimize f(X) Subject to $g(X_1, X_2, X_3........Xn) < 0$

Where X and g (X) represents the objective function and a Scalar function. Optimization, value of the constraints should be less than zero. To satisfy this condition, upper limits of each of the constraints is included in the constraint equation, so that each of the constraints is kept below (or) equal to the limit. The limits of the constraints (i.e heating time, hardness) were fixed based on the data obtained from the past experience with a view that they should provide a good heating process with a feasible solution to the objective function.

Also the constraints were given in the form of equations. General numerical methods are available for optimization of non-linear equations with constraints.

Use Of Matlab Software For Annealing Process :

Step: -1 Using M – File

Function (f, g) = f (X)

$$f(X) = 1150.4 - 170.7 * X_1 - 85.32 * X_2 + 1503 * X_1^2 + 1528 * X^2_2$$

This is the function ot be minimized (i.e) Total heating cost.

$$G(1) = 5.16 - 0.85 X_1 - 1.70 X_2 + 0.73 X_1^2 + 4.63 X_2 2 - 10.45$$

This is one of the constraint, and it is the total heating Time

$$G(2) = 98.04 - 0.13 x_1 - 0.30 X_2 + 0.94 X_1^2 - 0.16x_2^2 - 0.8x1 x^2 - 99$$

$$G(3) = F - 1500$$

$$G(4) = -F + 900$$

This states that the maximum limit is Rs. 1500/- and the minimum limit is Rs.900/- (Heating cost)

Invoke An Optimization Routine (R – File)

Step: 2

X0 = [-1, 1];

OPTIONS (14) = 10,000;

Vlb = [-1, -1];

Vub = [1, 1];

x = Constr ('f (x)' , X0, OPTIONS, Vlb, Vub)

Running the M-File:

Step: 3

After running the M-file and the constraints, the optimum values of the process variables are: as follows.

Results Of Mat Lab Software

OPTIMUM VALUES: FOR ANNEALING PROCESS

Process Variables: $X_1 = 0.0568$

$X_2 = 0.0279$

X_1 = Rate of heating = $150^{\circ}C$

X_2 = Rate of cooling = $75^{0}C$

Constraints

$g_1 = -5.3798$

$g_2 = -0.9741$

$g_3 = -355.6486$

$g_4 = -244.3614$

$g_1 = \text{equation} - 10.45 = -5.4$

TIME

$g_1 = 5.16 - 0.85 X_1 - 1.70 X_2 + 0.73 X_1^2 + 4.63 X_2^2 - 10.45 = -5.4$

$= 5.05$ hours

HARDNESS $= g_2 = 98.04 - 0.13 X_1 - 0.30 X_2 + 0.94 X_1^2 - 0.16 X_2^2 - 0.8 X_1 X_2 = 99 - 0.971$

$= 98.0259$

MAX COST $= g_3 = f - 150 = -355.6386$

$f = 1500 - 356 = 1144$

MIN COST $= g_4 = f + 900 = -244.3614 \Rightarrow -f = -900 - 244.3614$

$f = 1144$

Optimum Values For Normalising Process

PROCESS VARIABLES $X_1 = 1.0000$

$X_2 = 0.5332$

Rate of Heating $X_1 = 200^0C$

Heating Temp $X_2 = 875^0C$

The value of objective cost function is Rs. 750

Constraints

$g_1 = 0.0036$

$g_2 = -0.0051$

$g_3 = 1.0000$

$g_4 = 0.000$

TIME = g (1) = 4.7 - 1.4 x1 + 0.132 x2 + 0.19 x12 - 0.15 X22 - 0.14 X1 X2 - 7 = 0.0036

= 7.0036 Hours

HARDNESS = g (2) = 94 - 3.533 X1 - 1 X1 X2 - 95 = -0.0051

94 - 3.533 X1 - 1.X1 X2 = 95 - 0.0051

= 94.99 = 95

MAX COST = g_3 = f -1750 = -1

f = 1750 -1 =1749

MIN COST = g_4 = -f + 750 = 0 = f = + 750 => f = 750

7.2 Validation Of The Mathematical Model :

Scatterd Diagram

Annealing : Response (y_1) = Cost.

Heating Cost $= 1150.4 - 170.7R_H - 85.35\ R_C + 1503\ R^2_H + 1528\ R^2_C$

Observed Values	Predicted Values
1500	1437.4
1100	1096.05
1300	1266.75
900	925.35
1350	1396.85
950	914.13
1300	1326.15
1100	1084.78
1150	1150.4
1150	1150.4
1150	1150.4
1150	1150.4
1150	1150.4

Table – 10

Annealing Response (y2) = Hardness

Observed Values	Predicted Values
98	98.45
99	99.79
99	99.45
97	97.59
98	98.9
98	98.73
97	98
97	97.3
97	98
99	98.7
99	98.7
99	98.7
98	98.7

Table – 11

Annealing Response (y3) = Heating time

Observed Values	Predicted Values
12	12.07
10	10.37
8	8.59
6	6.7
9.15	8.81
7.15	7.41
10.45	10.4
6.45	7.01
8	7.56
8	7.56
8	7.56
8	7.56
8	7.56

Table - 12

Normalizing Response (Y1) = Cost

Observed Values	Predicted Values
1700	1559.07
750	730.57
1750	1619.42
800	790.92
1750	1810.62
750	739.14
900	950
1000	1067
950	950
950	950
950	950
950	950
950	950

Table - 13

Normalizing Response (Y2) = Hardness

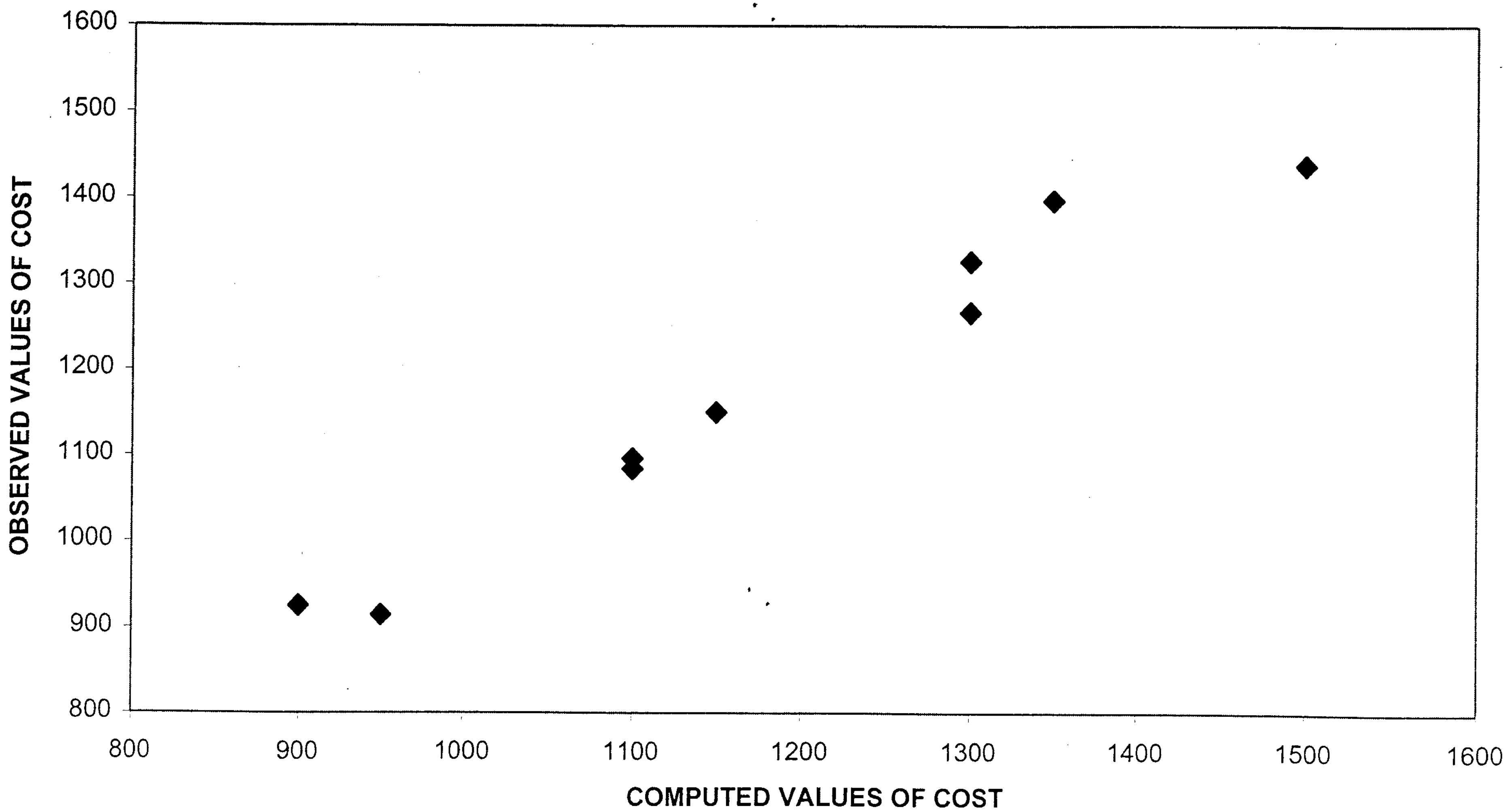
Observed Values	Predicted Values
93	96.53
95	91.46
95	98.5
93	91.4
95	94
93	91.4
94	94
94	94
94	94
94	94
94	94
94	94
94	94

Table - 14

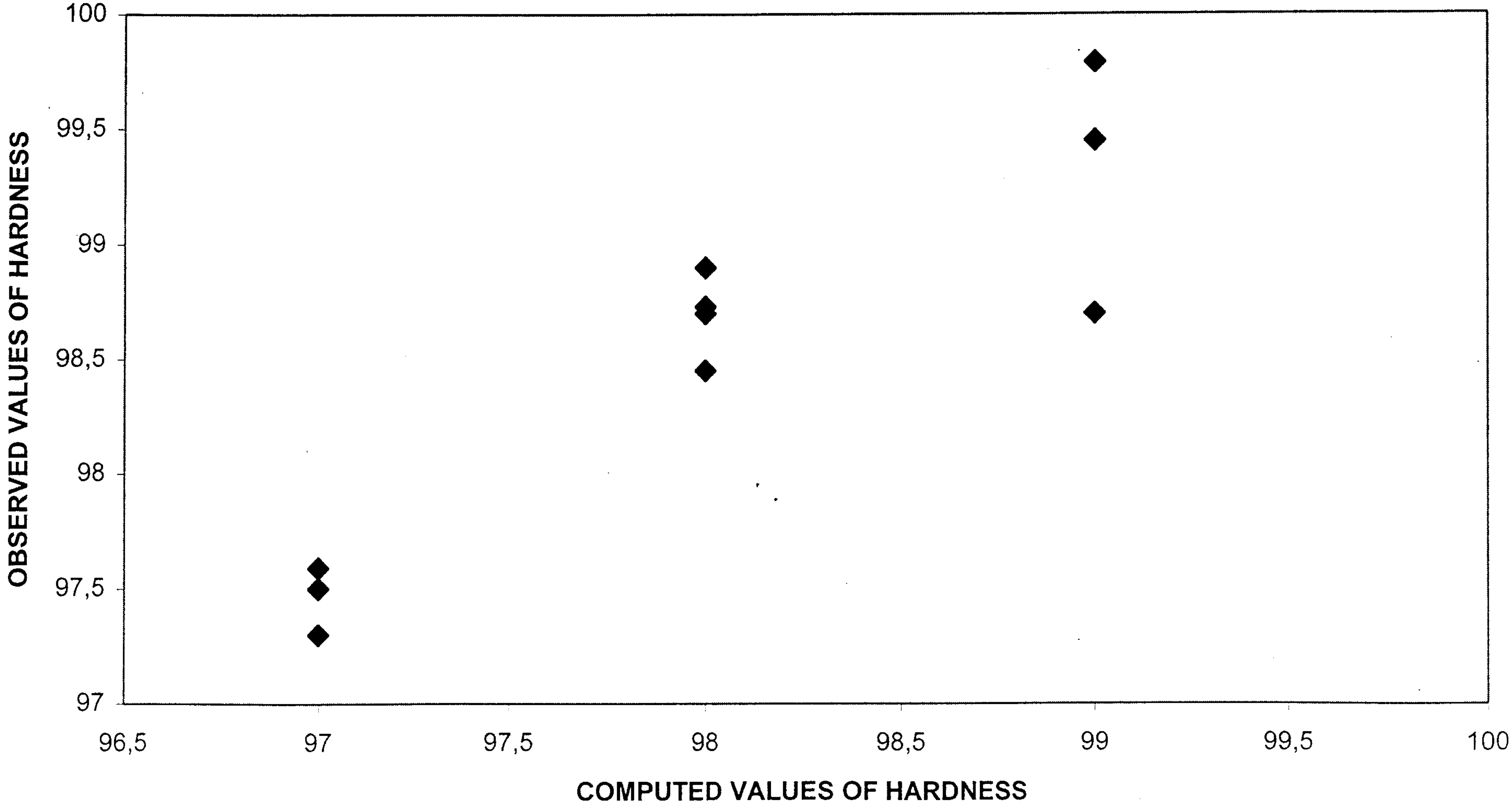
Normalizing Response (Y3) = Heating time

Observed Values	Predicted Values
6.30	6
3.15	3.34
7	6.42
3.30	3.33
6.45	7.04
3.30	3.10
4.15	4.22
4.30	4.59
4.30	4.56
4.30	4.56
4.30	4.56
4.30	4.56
4.30	4.56

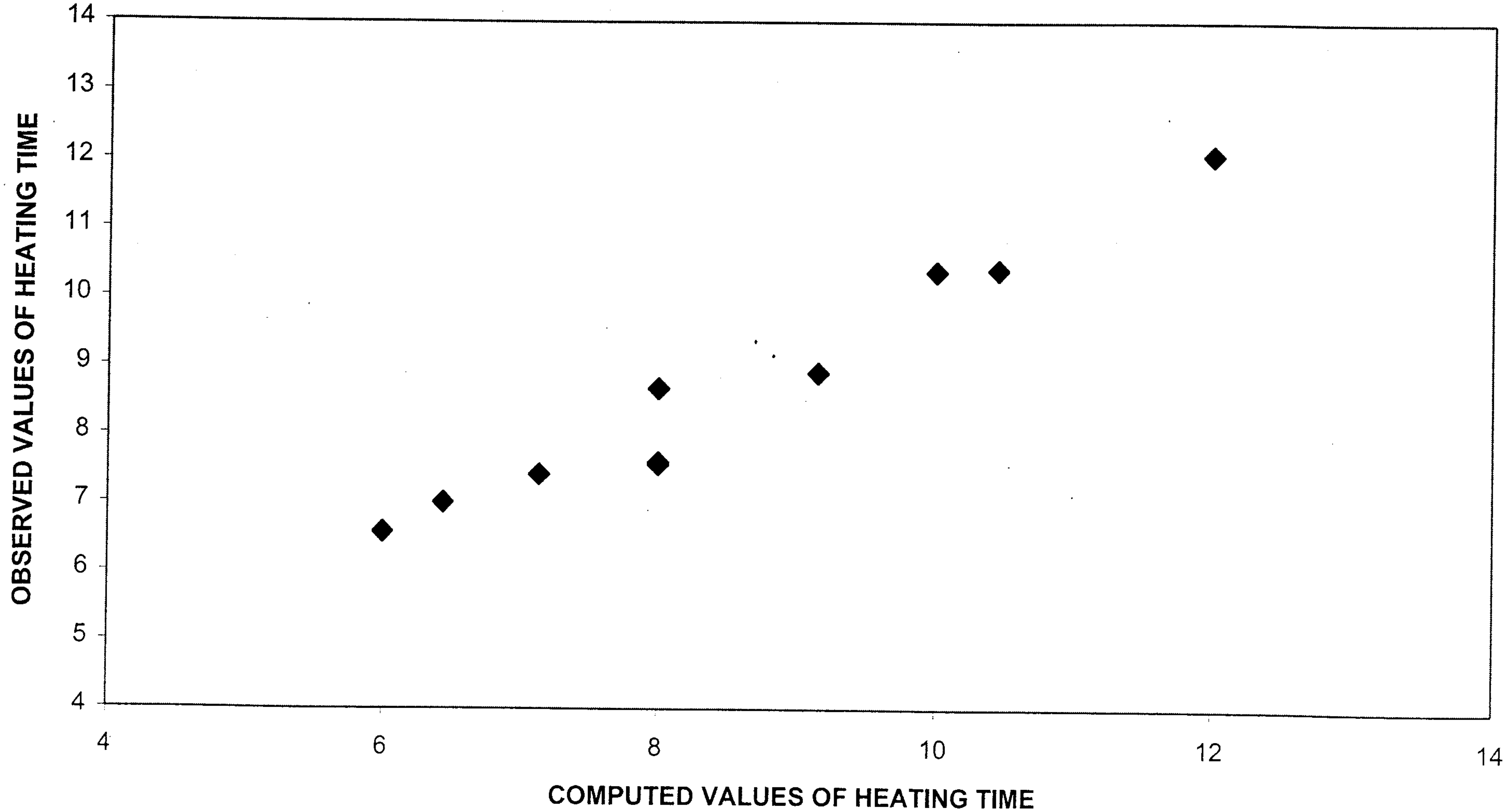
Table - 15



SCATTER DIAGRAM FOR COST
Chart - 1

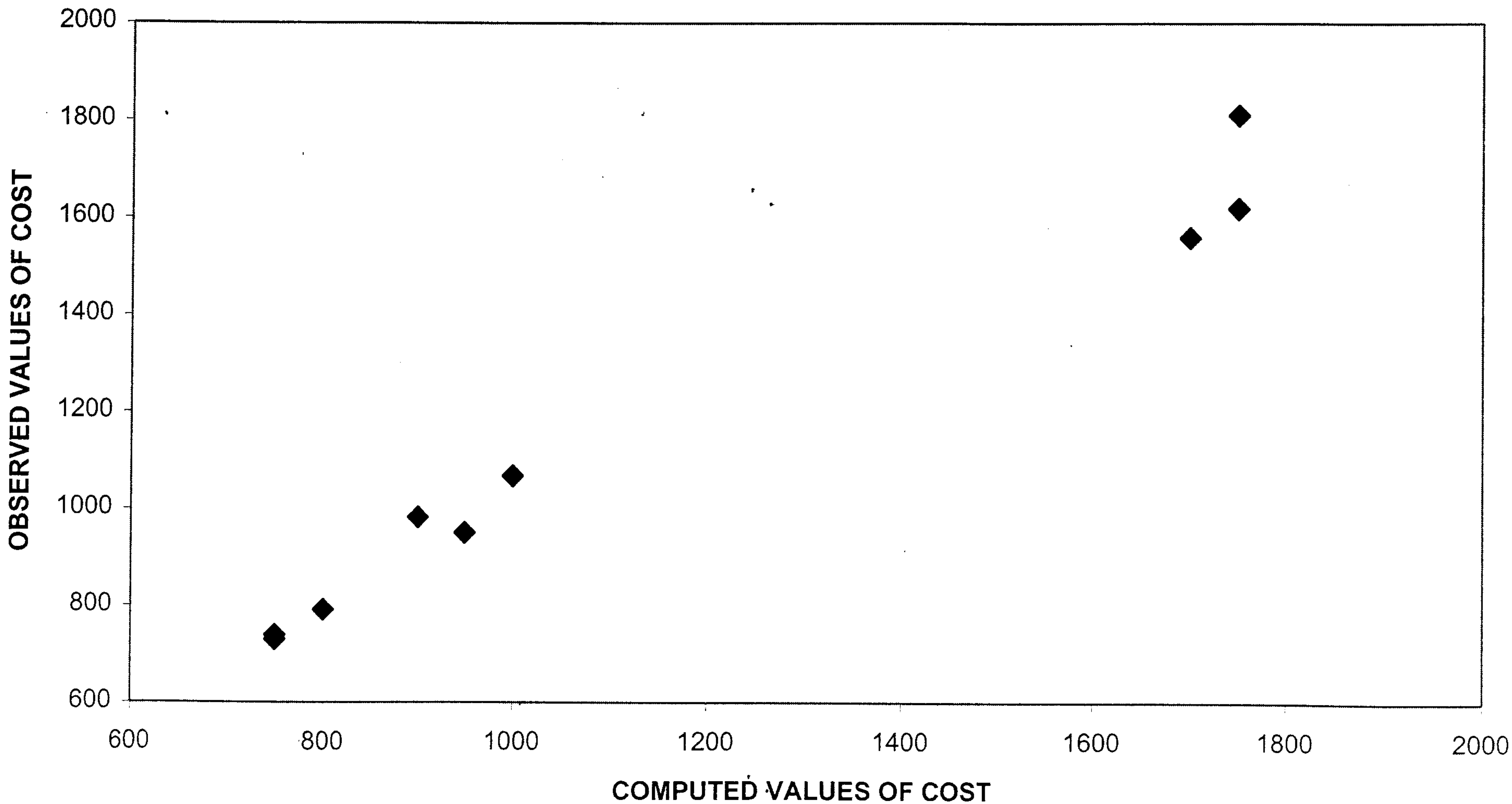


SCATTER DIAGRAM FOR HARDNESS
Chart - 2



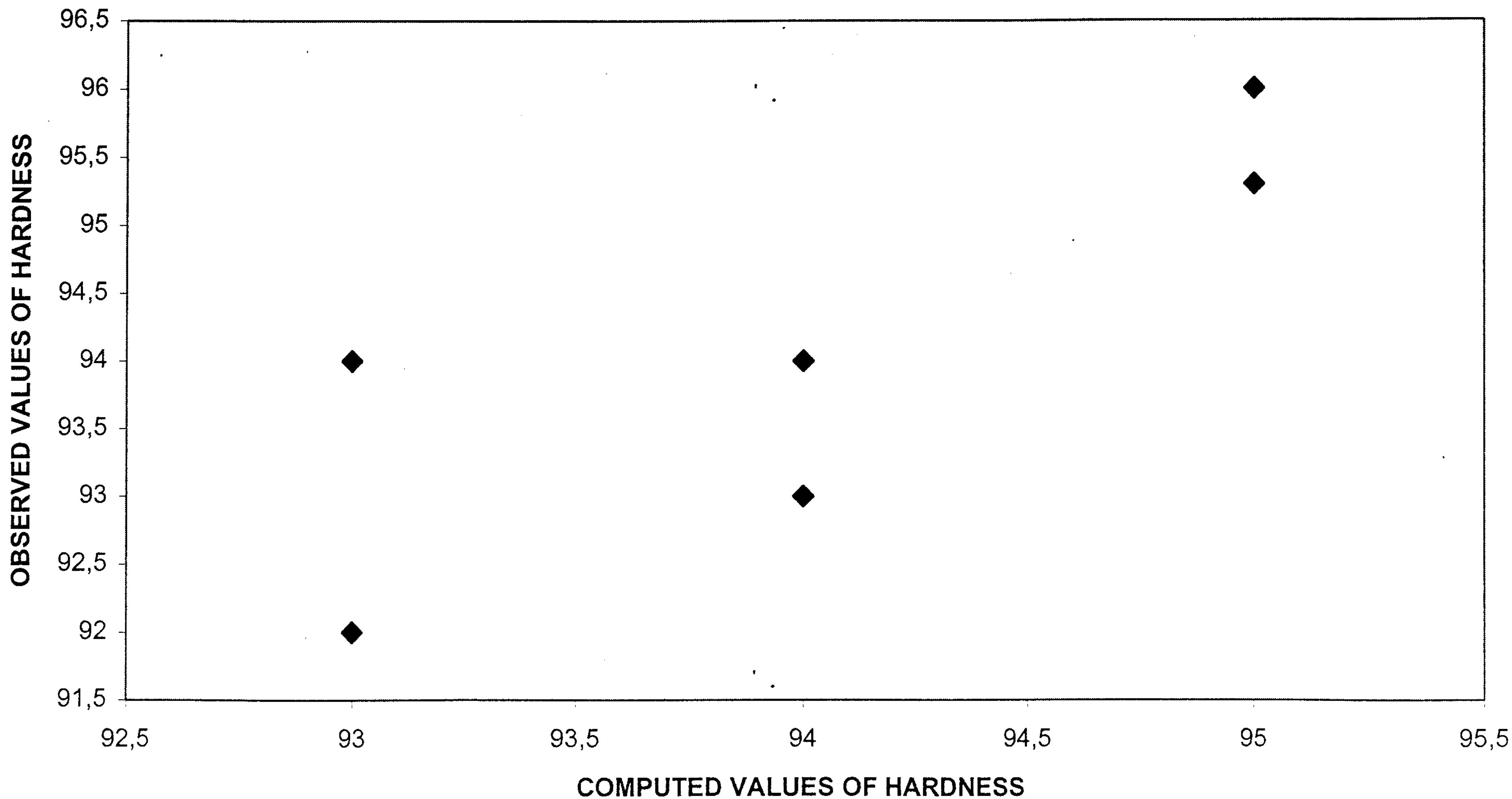
SCATTER DIAGRAM FOR HEATING TIME

Chart - 3



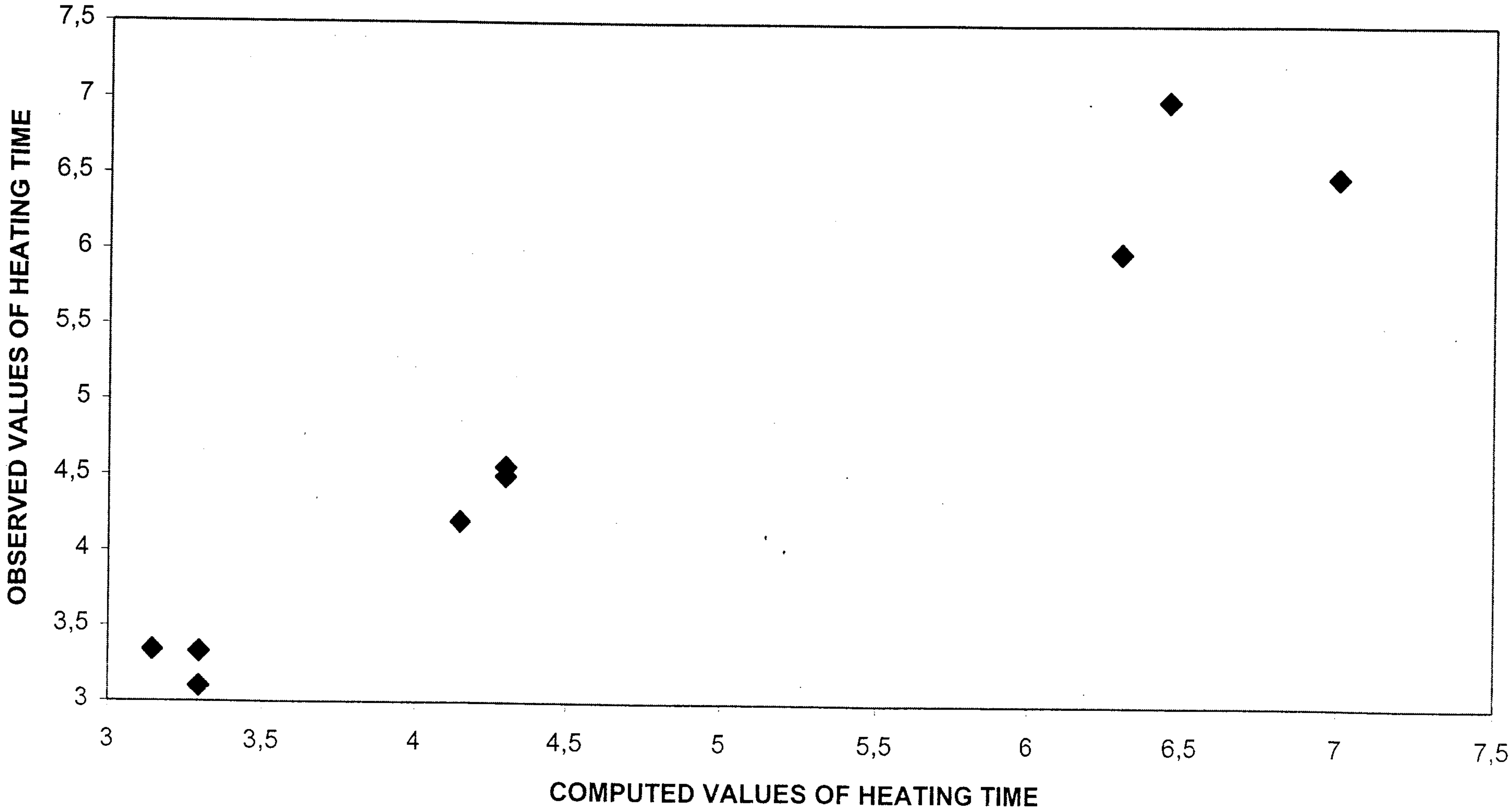
SCATTER DIAGRAM FOR COST (NORMALISING)

Chart - 4



SCATTER DIAGRAM FOR HARDNESS (NORMALISING)

Chart - 5



SCATER DIAGRAM FOR HEATING TIME (NORMALISING)

Chart - 6

7.22 Validation using SYSTAT Software

SYSTAT Software is used to verify the accuracy of regression co-effecients being calculated to obtain the mathematical model.

Annealing

Heat treatment cost = $1150.4 - 170.7\,X_1 - 85.35X_2 + 1503X_1^2 + 1528\,X_2^2$

Co-efficient values obtained from SYSTAT Software

Variable	Co-efficient
Constant	1130
X_1	-170.76
X_2	-75.36
$X_1 * X_1$	1488
$X_2 * X_2$	1510
$X_1 * X_2$	0

Table - 16

Mathematical Model for hardness

$$= 98.04 - 0.13X_1 - 0.30X_2 + 0.94X_1^2 - .16X_2^2 - 0.8X_1X_2$$

Coeffecients values obtained from SYSTAT Software For Hardness

Variables	Co-Efficient
Constant	96.3
X_1	-0.1
X_2	-0.30
X_1*X_1	0.8
X_2*X_2	-0.14
X_1*X_2	0.7

Table - 17

Mathematical Model for Heating time

$$= \quad 5.16 - 0.85X_1 - 1.70X_2 + .73X_1^2 + 4.63X_2^2$$

Coefficient values obtained from SYSTAT Software for Heating Time

Variables	Co-Efficient
Constant	4.8
X_1	-0.9
X_2	-1.5
X_1*X_1	0.8
X_2*X_2	4.5
X_1*X_2	0

Table - 18

Normalising

Heat Treatment Cost

$$= \quad 950 - 414.25X_1 + 30.175X_2 + 187.5X_1^2 + 37.5X_2^2$$

Coefficient values obtained from SYSTAT Software for Heating Cost

Variables	Co-Efficient
Constant	930
X_1	-410
X_2	25
X_1*X_1	176
X_2*X_2	33
X_1*X_2	0

Table - 19

Heat Treatment Time

$$= \quad 4.7 - 1.4X_1 + 0.132X_2 + .19X_1^2 - .15X_2^2 - .14X_1 * X_2$$

Coefficient values obtained from SYSTAT Software for Heating Time

Variables	Co-Efficient
Constant	3.5
X_1	-1.3
X_2	0.132
$X_1 * X_1$	0.18
$X_2 * X_2$	-0.13
$X_1 * X_2$	-0.12

Table - 20

Heat Treatment Hardness

$$= \quad 94 - 3.53X_1 - 1X_1{*}X_2$$

Coefficient values obtained from SYSTAT Software for Heating Hardness

Variables	Co-Efficient
Constant	94
X_1	-3.3
X_2	0
$X_1{*}X_2$	-1

Table - 21

7.3 Confirmity Test :

Annealing Process

The Optimum process variables obtained for annealing process are as follows :

Rate of Heating = 150^0C / hour

Rate of Cooling = 75^0C / hour

On conducting the experiments, by keeping the values of process variables as above the heating cost was found to be Rs. 1144/- which is equal to the value of the objective cost function obtained from the MATLAB Software.

Normalising Process :

The Optimum process variables obtained for normalising process are as follows

Rate of Heating = 200^0C / hour

Heating Temperature = 875^0C / hour

On conducting the experiment by keeping the values of process variables as above, the heating cost was found to be Rs. 750 which is equal to the value of the objective cost function obtained from the MATLAB Software.

8. 1 Annealing Process:-

Direct Effect of Rate of Heating on cost :-

It is from the graph that when at constant rate of cooling of 75· C/hr, heating cost is Rs.2823.45, where rate of heating is 100· C/hr. The heating cost is found minimum [Rs.1150.4], when the rate of heating is 150· c/hr.

Direct Effect of Rate of cooling on cost :-

The rate of heating is kept constant at 150· c/hr, and cost for different rate of cooling is derived. Cost is minimum, when the rate of cooling is 75· c/hr. [Rs.1150.4].

Interaction Effect of Rate of Heating & Rate of cooling on cost :-

The combined effect of different levels of rate of heating and rate of cooling are analysed. When rate of heating is 100· C/hr and rate of cooling is 50^{0} C/hr, it leads to maximum amount of heating cost [Rs.5586.484]. For all levels of rate of cooling, heating cost is minimum, at the rate of heating of 150^{0} C/hr. But when rate of cooling increase, we find gradual decrease in the heating cost. Also, heating cost is minimum [Rs.1140.40] when rate of heating is 150^{0} C/hr and rate of cooling is 100^{0} C/hr.

Direct Effect of Rate of Heating on heat ing time :-

When rate of heating is 100^{0} C/hr, the heating time is 7 hours. Similarly when rate of heating is 200^{0} C/hr, the heating time is 5 hours. So, as the rate of heating hour increases, the heating time decreases.

Direct Effect of Rate of cooling on heating time :-

It is obvious that, when rate of cooling increases, heating time decreases at constant rate of heating.

Direct Effect of Rate of heating on hardness :-

The observed hardness value, for the three levels of rate of heating and rate of cooling are within the admissible range from the graph we see that at constant rate of cooling of 75^{0} C/hr, and when the rate of heating is 150^{0} C/hr there is a light decrease in hardness value.

Direct Effect of Rate of cooling on hardness :-

It can be seen from the graph that at constant rate of heating of 150^{0} C/hr, and for increasing temperatures of rate of cooling, there is a slight decrease in the hardness.

Interaction Effect of Rate of Heating and rate of cooling on Heating Time:-

The combinational effect of different levels of rate of heating and rate of cooling are examined. It can be seen t hat maximum heating time occurs, when rate of heating is 100^{0} C/hr and rate of cooling in 50^{0} C/hr. Similarly minimum heating time occurs when rate of heating is 150^{0} C/hr and rate of cooling is 50^{0} C/hr. We can see from the graph that when rate of heating increases, the heating time decreases.

8.2 Normalizing Process :-

Direct Effect of Rate of Heating on cost :-

It is evident from the graph that, when the rate of heating increases, there is a decrease in heating cost. Therefore it is better to have high rate of heating.

Direct Effect of Heating Temperature on cost :-

It is natural that when the heating temperature increases, there is steady increase in heating cost. This is represented in the graph.

Interaction Effect of Rate of Heating & Heating Temperature on cost :-

It is seen from the graph that the heating cost is maximum [Rs.1619.26], when the rate of heating is low and the heating temperature being high. It can also be seen that the heating cost is minimum, when the rate of heating is high and the heating temperature being less. So, the combinational effect of rate of heating and rate of cooling is thus studied.

Direct Effect of Rate of Heating on Heating Time:-

It is evident from the graph that the heating time is inversely proportional to the rate of heating. As the rate of heating is increased, the heating time is decreased.

Direct Effect of Heating Temperature on Heating Time:-

Heating time is diirectly proportional to the heaing temperature. It is seen from the graph that as the heating temperature increases, heating time also increases.

Direct Effect of Rate of Heating on Hardness :-

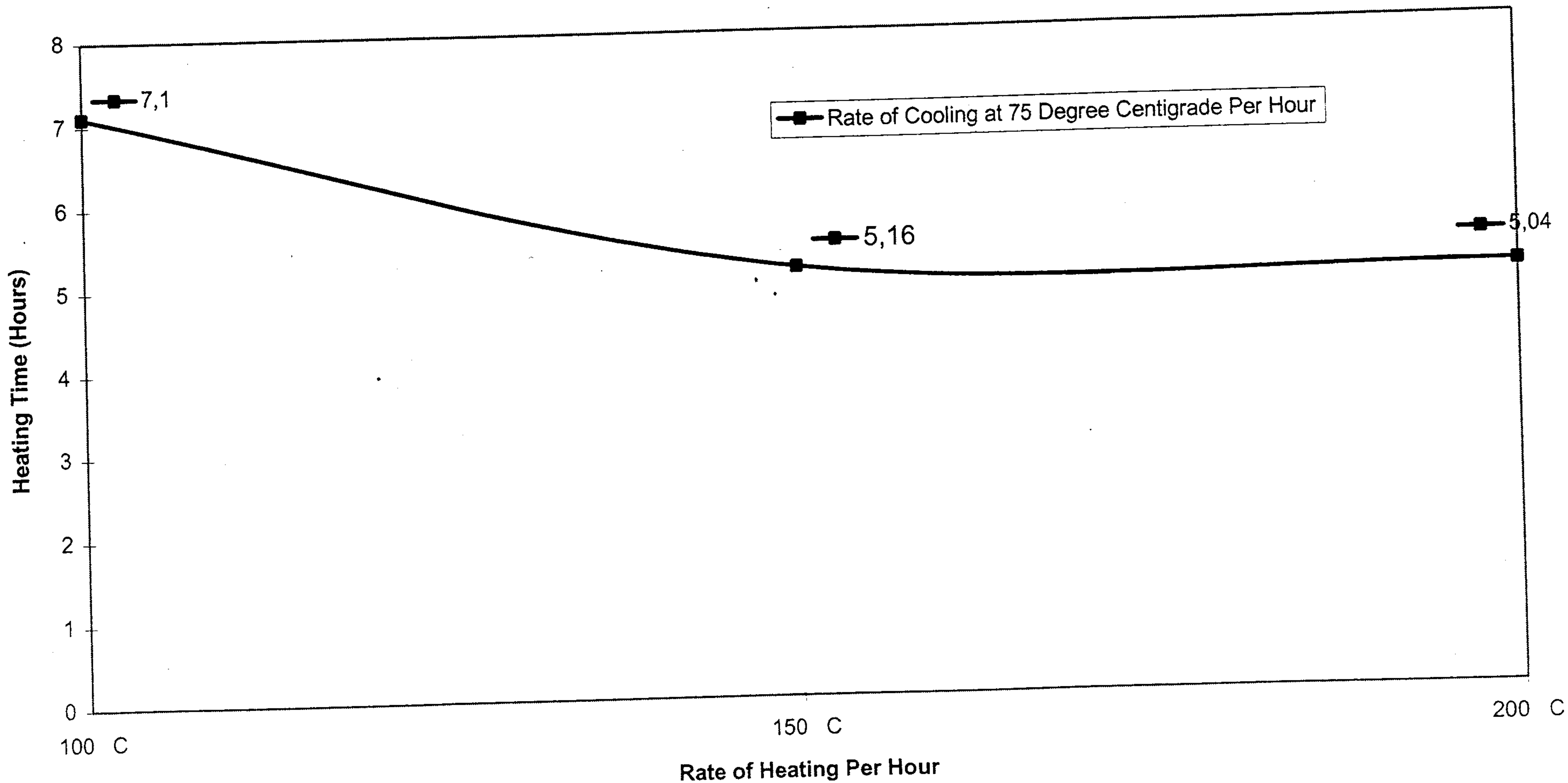
For the three different levels of rate heating, hardness is within the limits. It can be seen that as the rate of heat ing is increased hardness decreases.

Interaction Effect of Rate of Heating & Heating Temperature on Heating Time :-

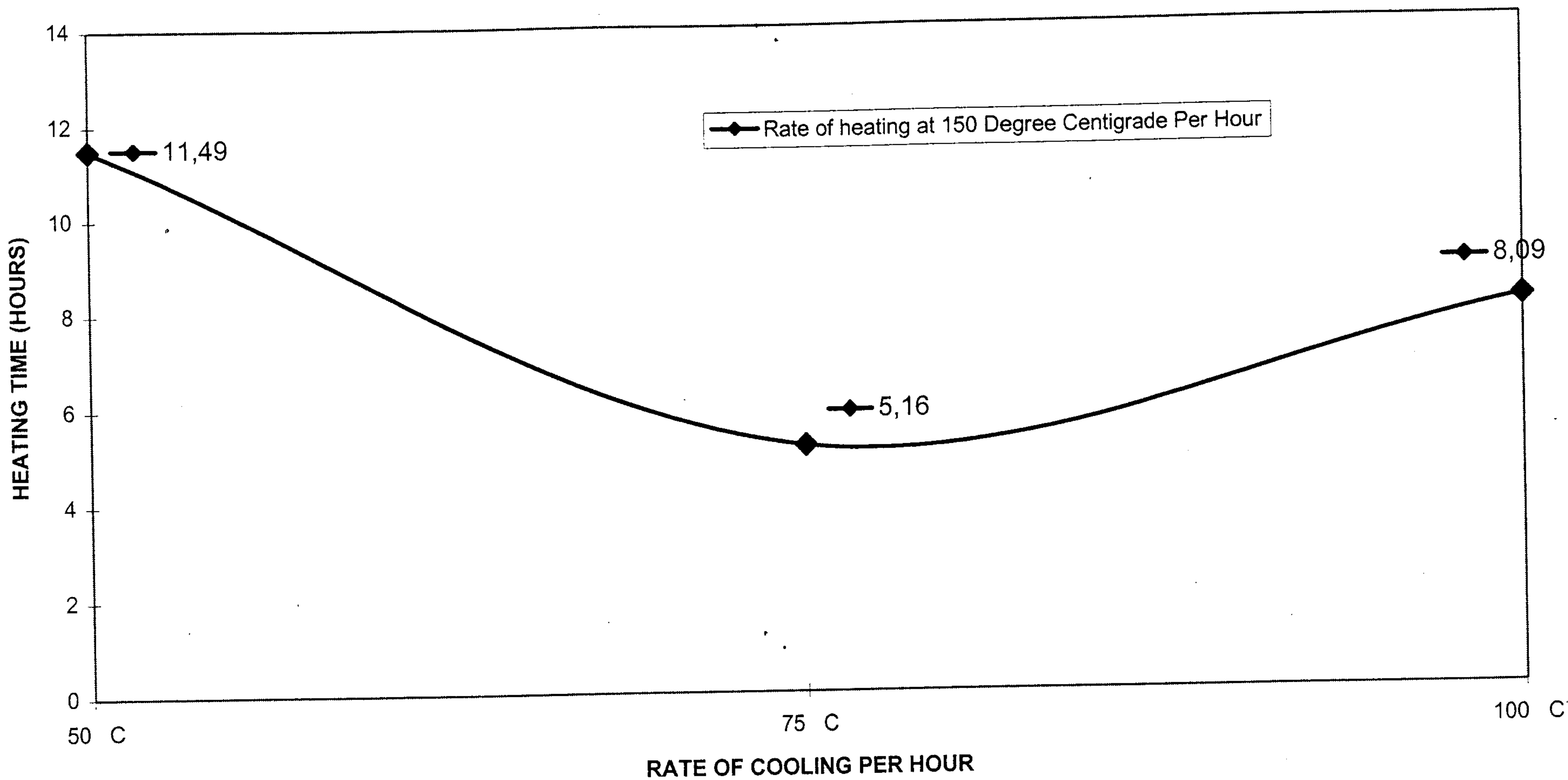
It is seen from the graph that heating time is higher where rate of heating is at minimum level and heating temperature is maximum. Similarly heating time is less, where rate of heating is maximum and heating temperature is minimum.

Direct Effect of Heating Temperature in Hardness :-

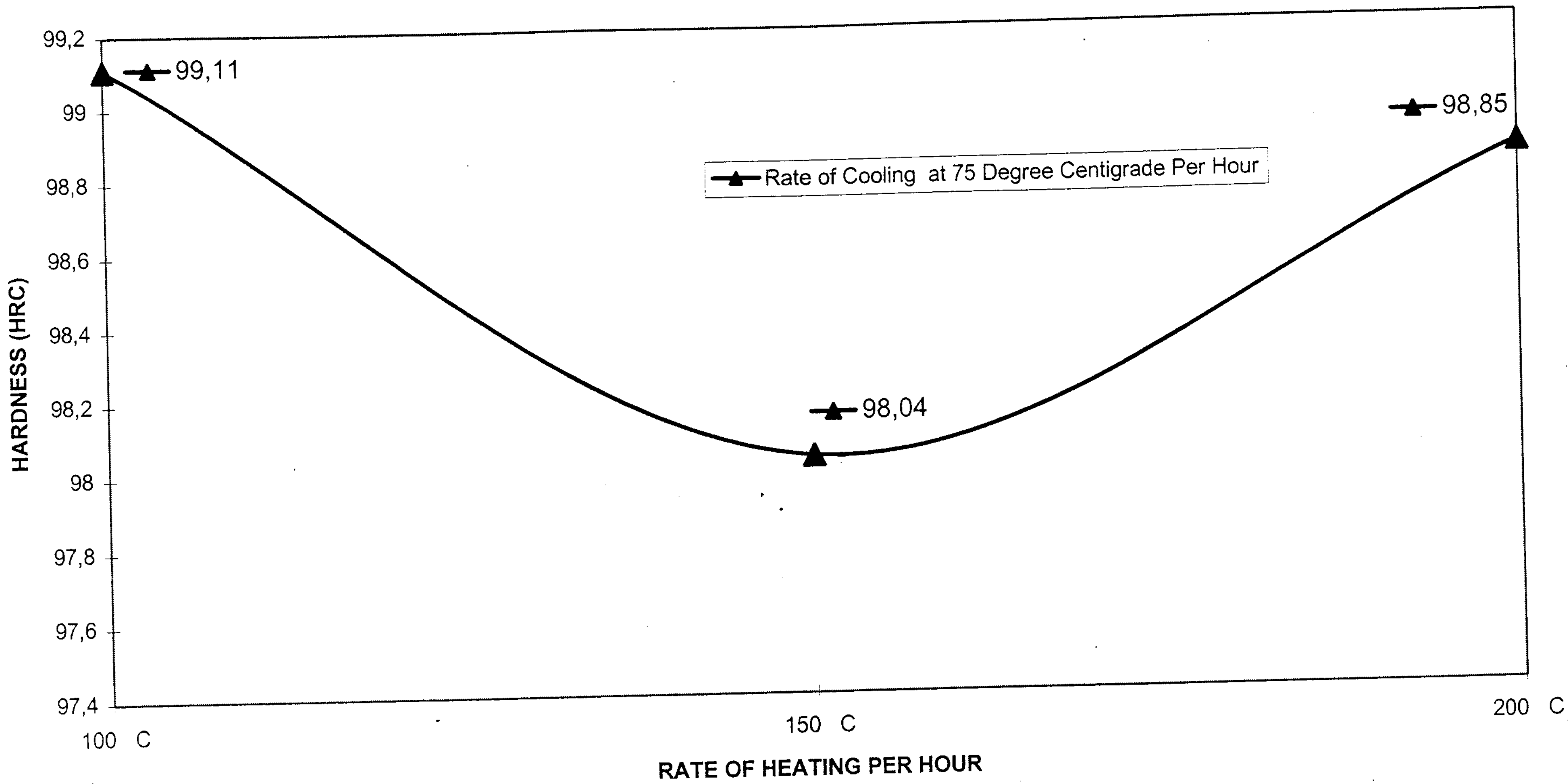
Since the temperature range is less the three levels of heating temperature have same effect on hardness and is shown in the graph.



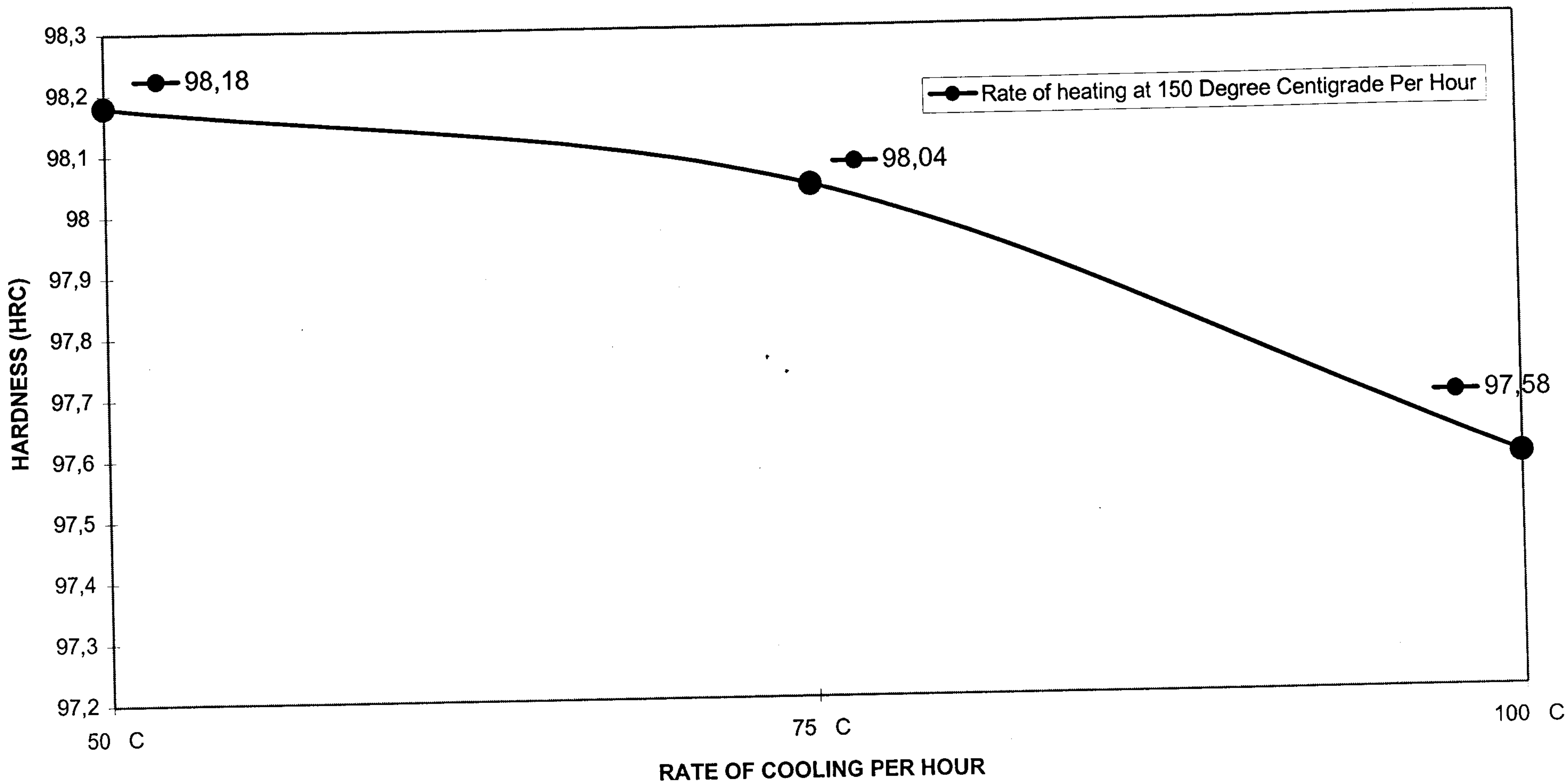
DIRECT EFFECT OF RATE OF HEATING ON HEATING TIME
Chart - 7



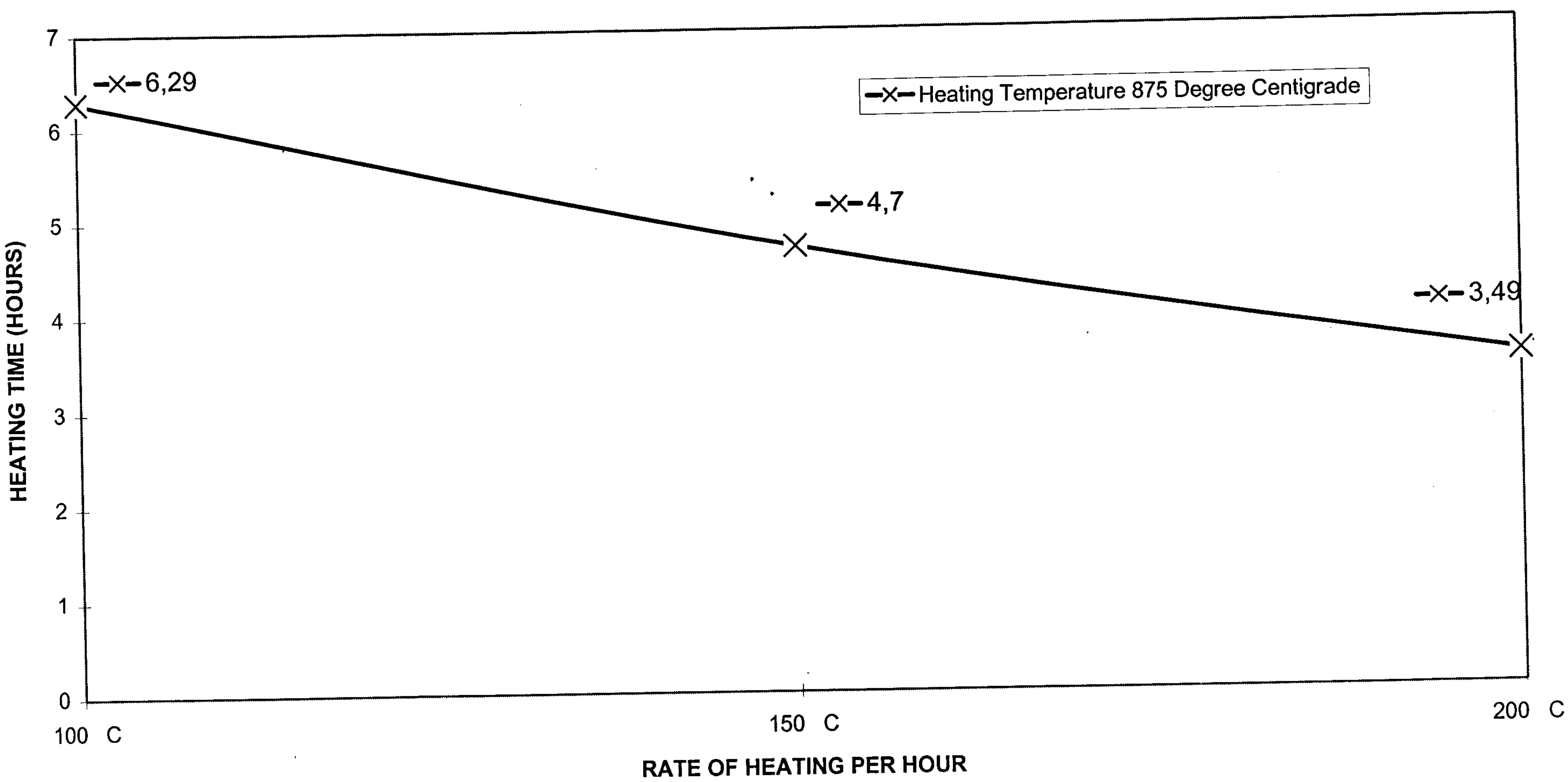
DIRECT EFFECT OF RATE OF COOLING ON HEATING TIME
Chart - 8



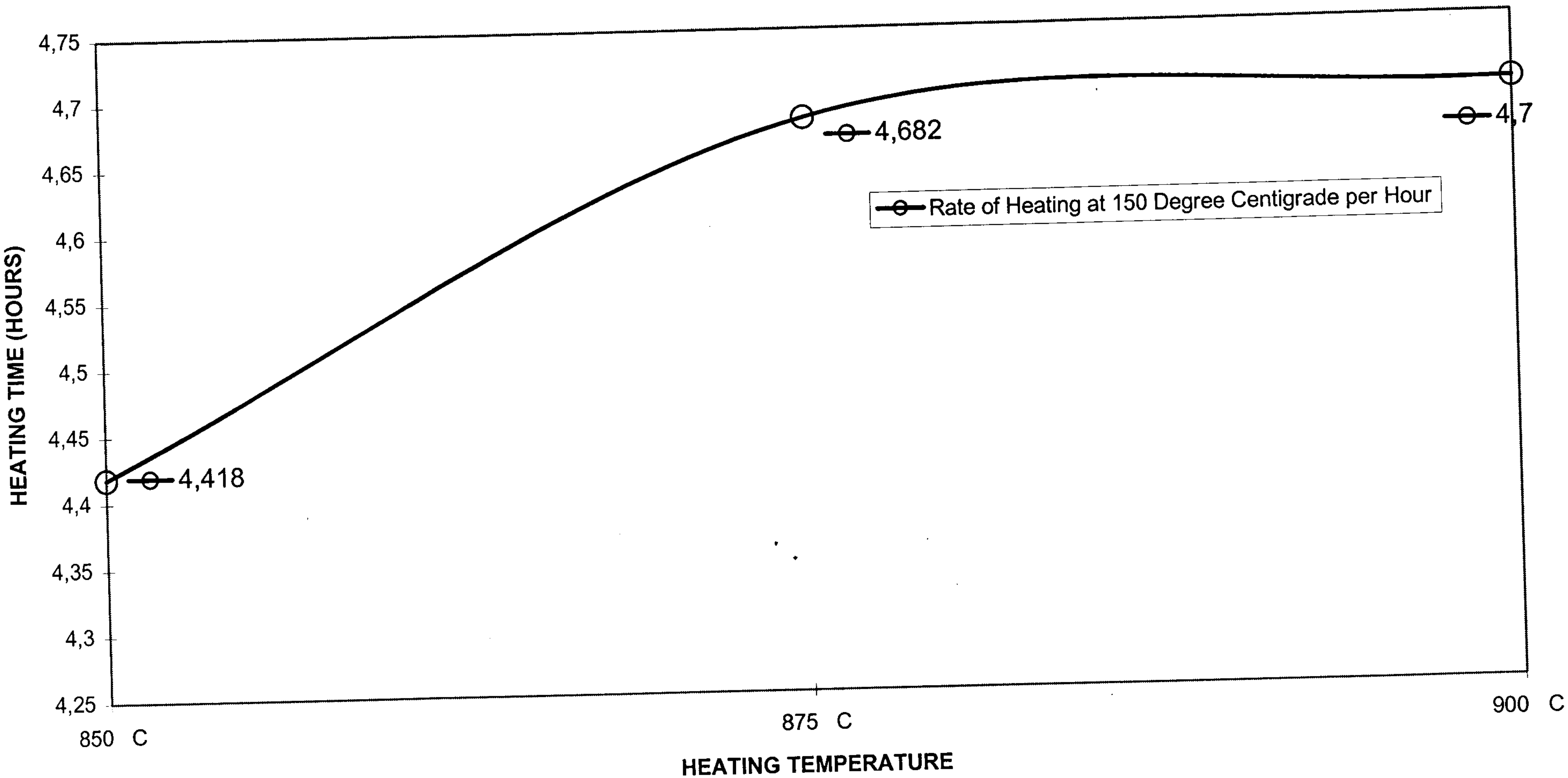
DIRECT EFFECT OF RATE OF HEATING ON HARDNESS
Chart - 9



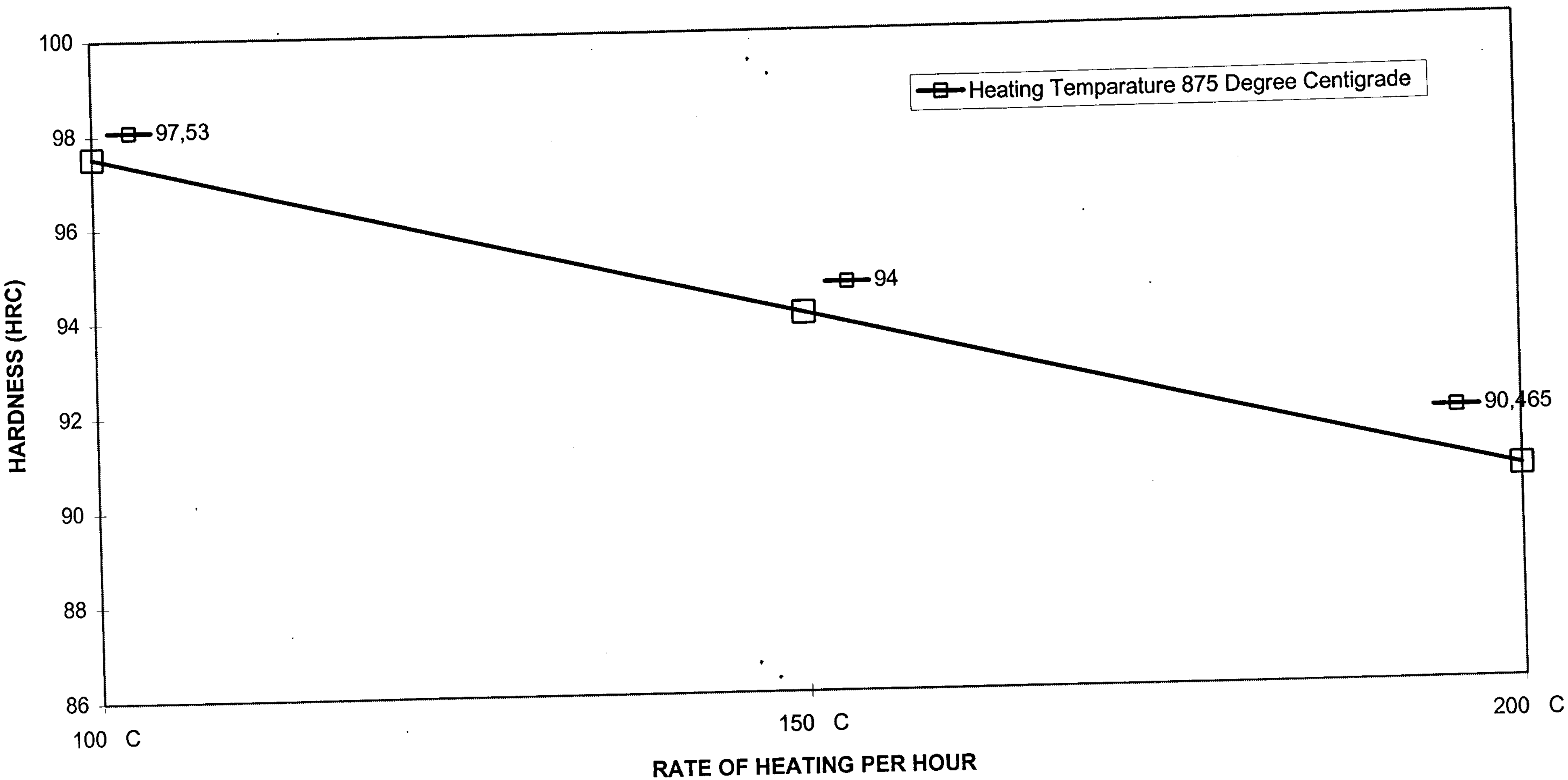
DIRECT EFFECT OF RATE OF COOLING ON HARDNESS
Chart - 10



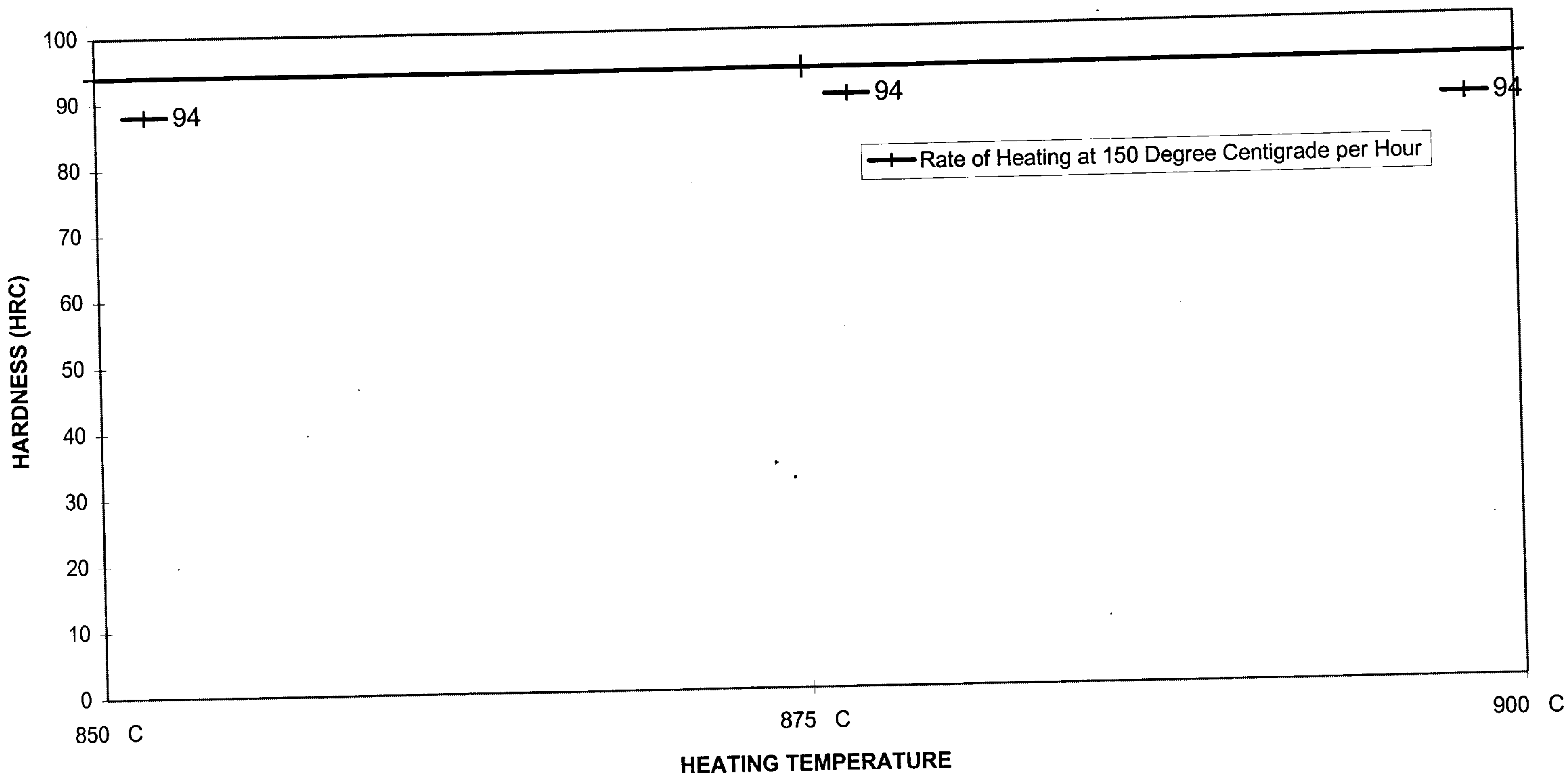
DIRECT EFFECT OF RATE OF HEATING ON HEATING TIME
Chart - 11



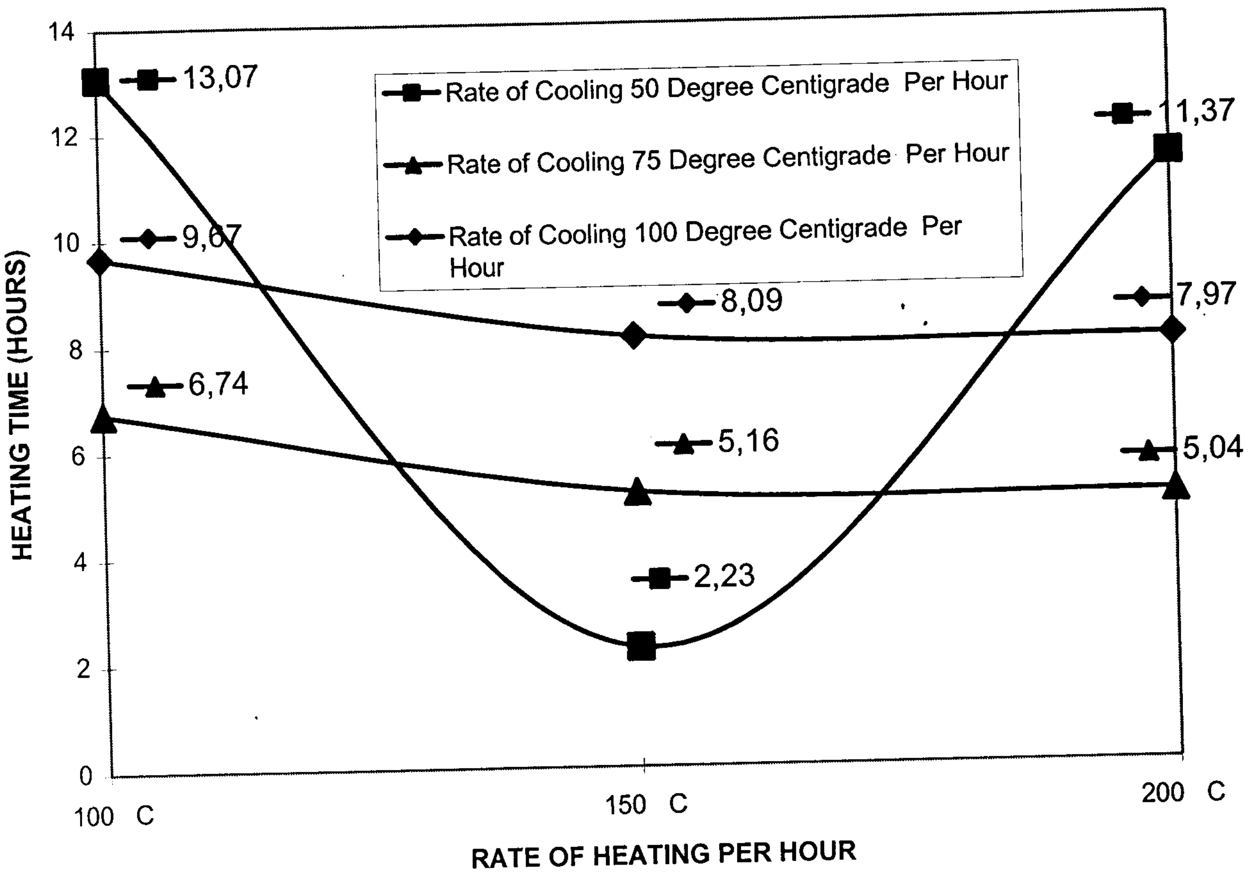
DIRECT EFFECT OF HEATING TEMPERATURE ON HEATING TIME
Chart - 12



DIRECT EFFECT OF RATE OF HEATING ON HARDNESS
Chart - 13

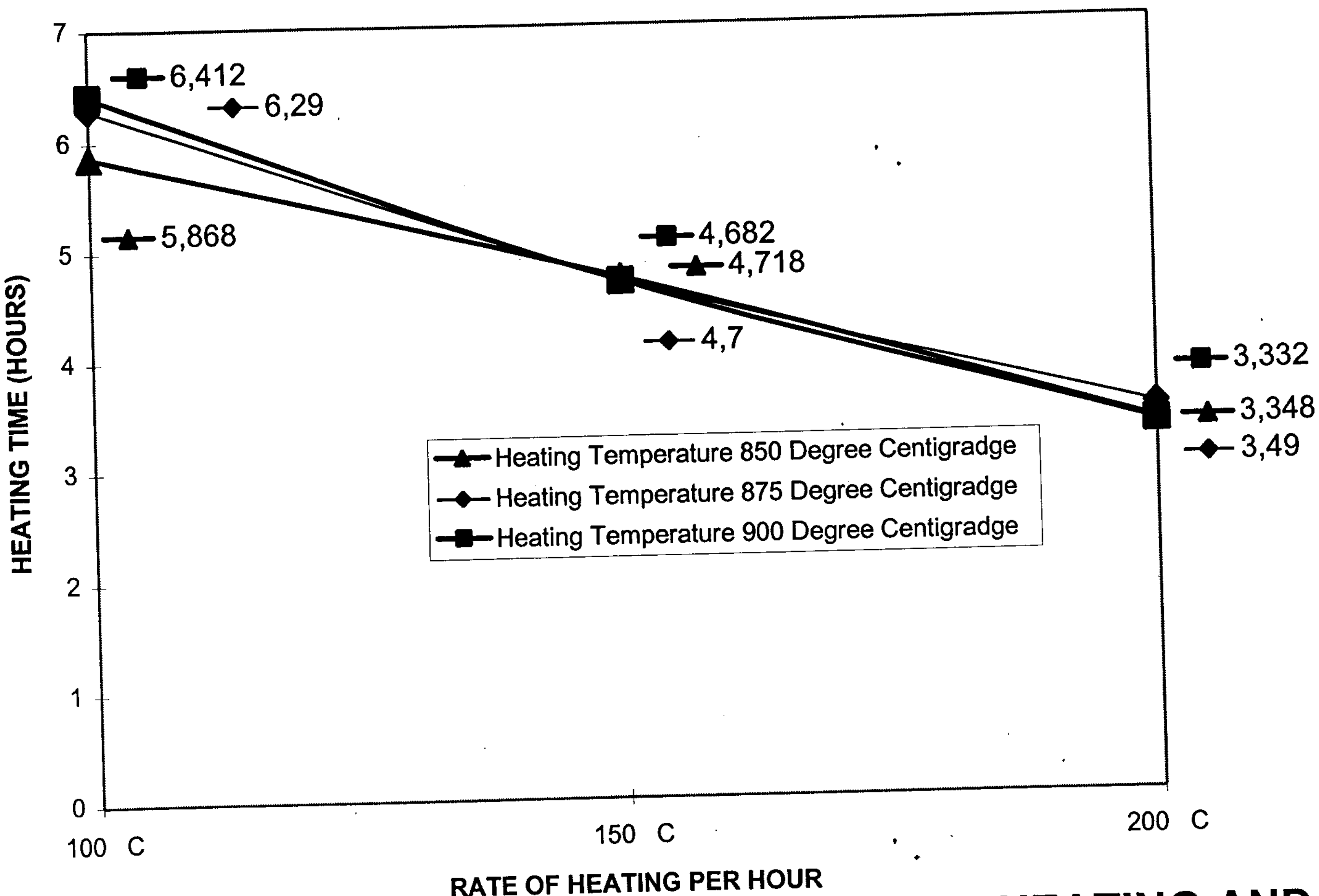


DIRECT EFFECT OF HEATING TEMPERATURE ON HARDNESS
Chart - 14



INTERACTION EFFECT OF RATE OF HEATING AND RATE OF COOLING ON HEATING TIME

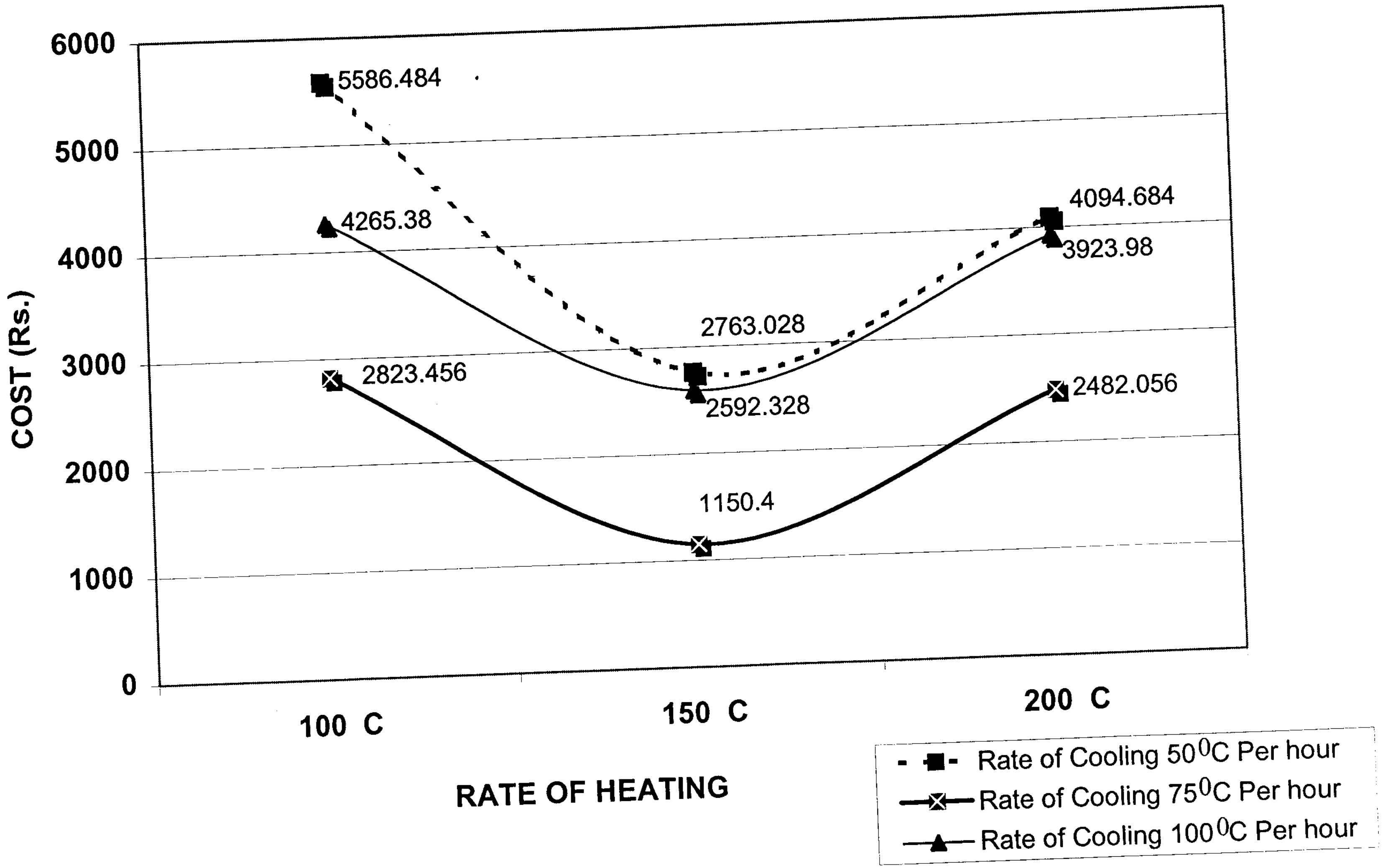
Chart - 15



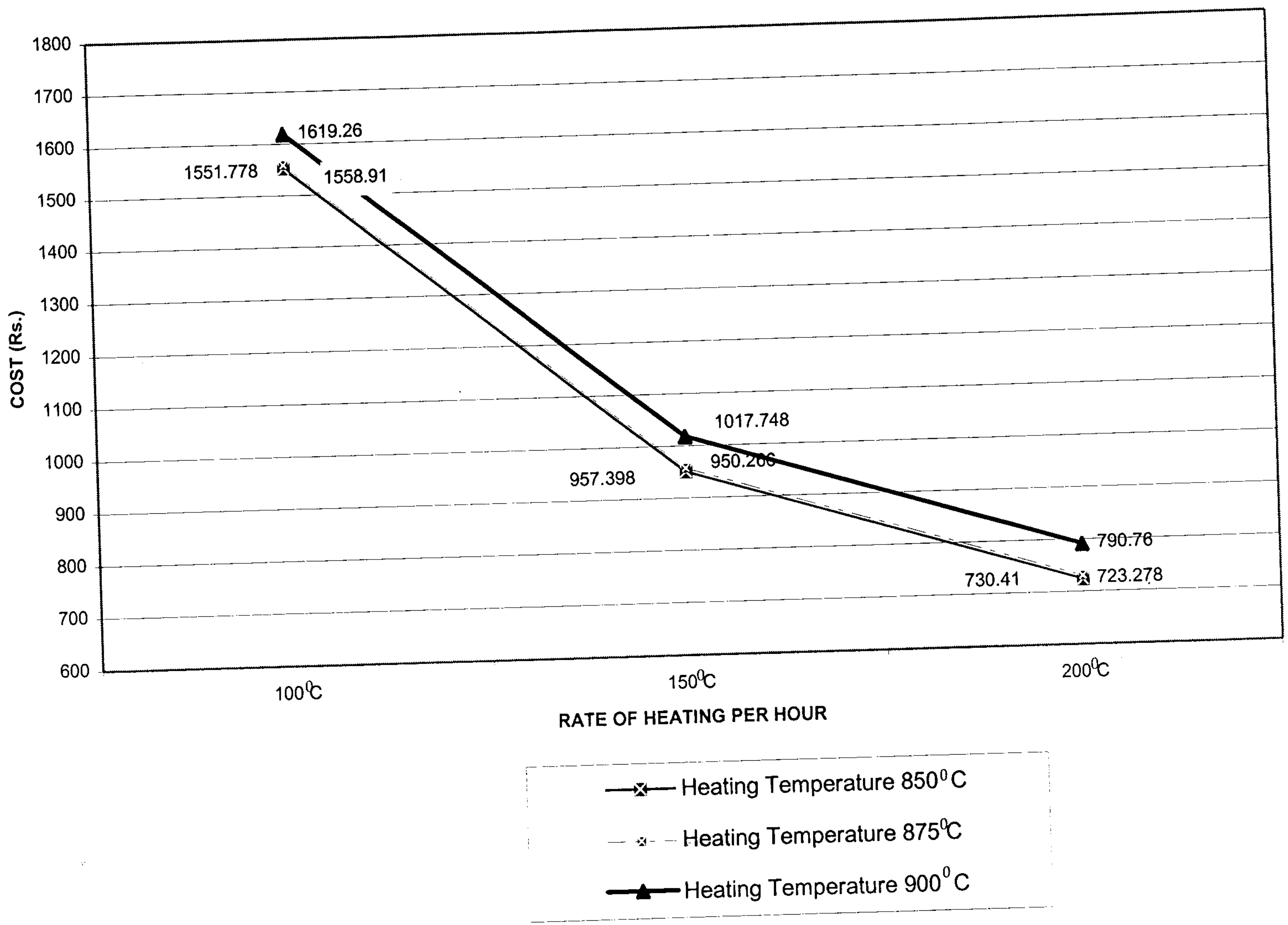
INTERACTION EFFECT OF RATE OF HEATING AND HEATING TEMPERATURE ON HEATING TIME

Chart - 16

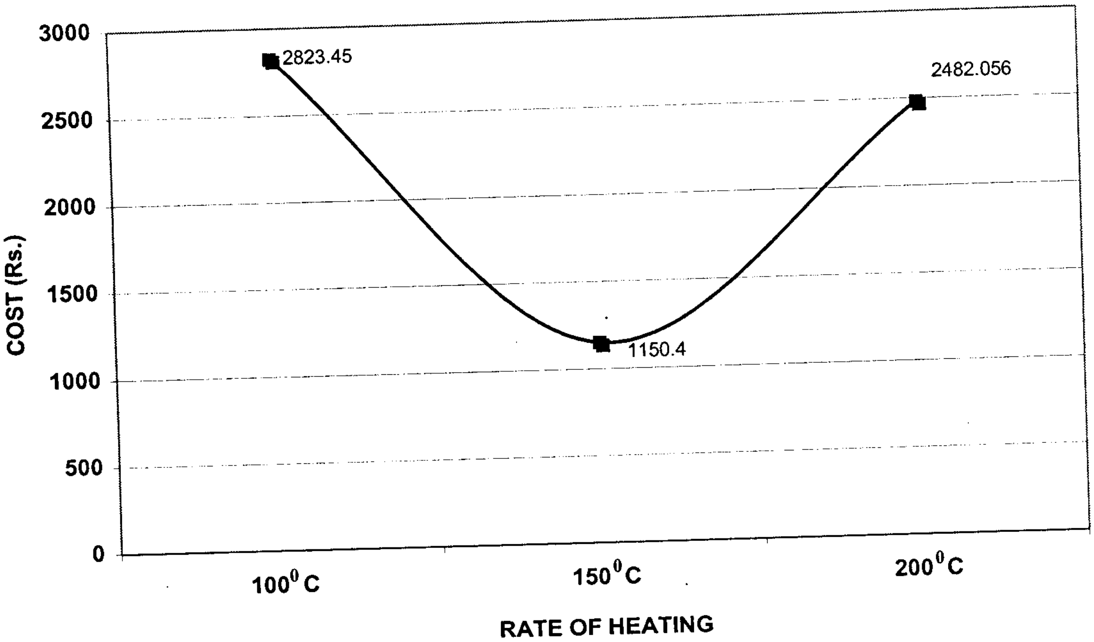
INTERACTION EFFECT OF RATE OF HEATING & RATE OF COOLING ON COST



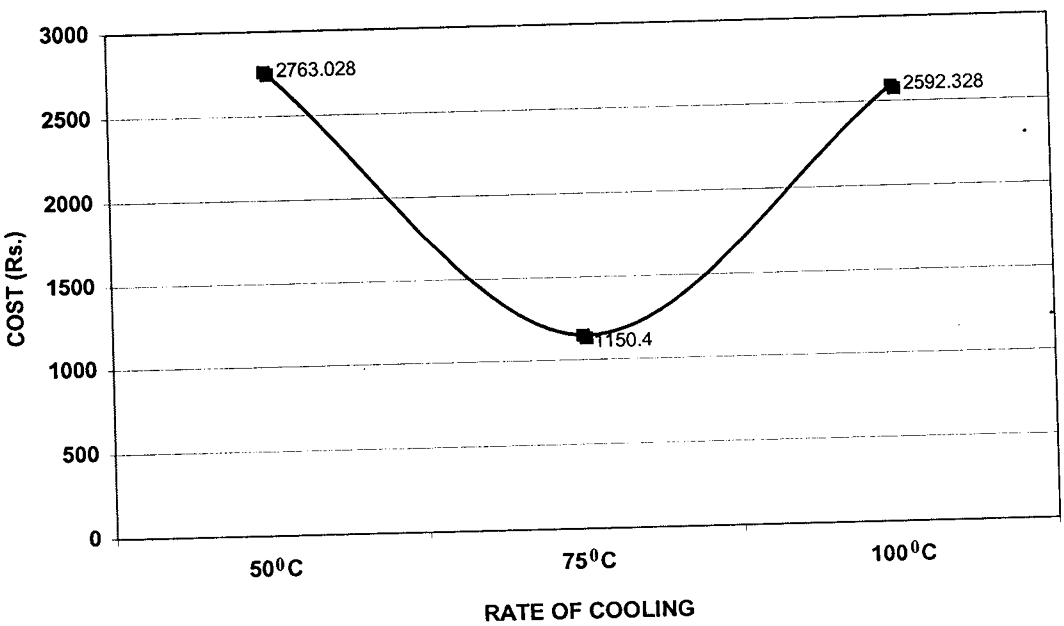
INTERACTION EFFECT OF RATE OF HEATING & HEATING TEMPERATURE ON COST

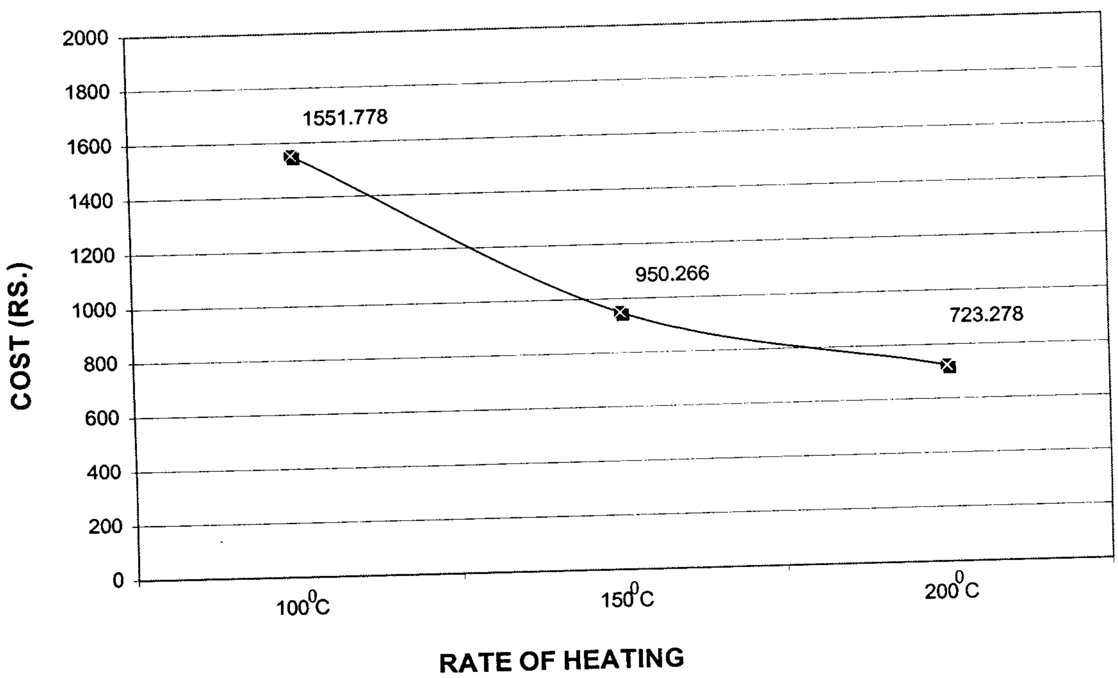


DIRECT EFFECT OF RATE OF HEATING ON COST

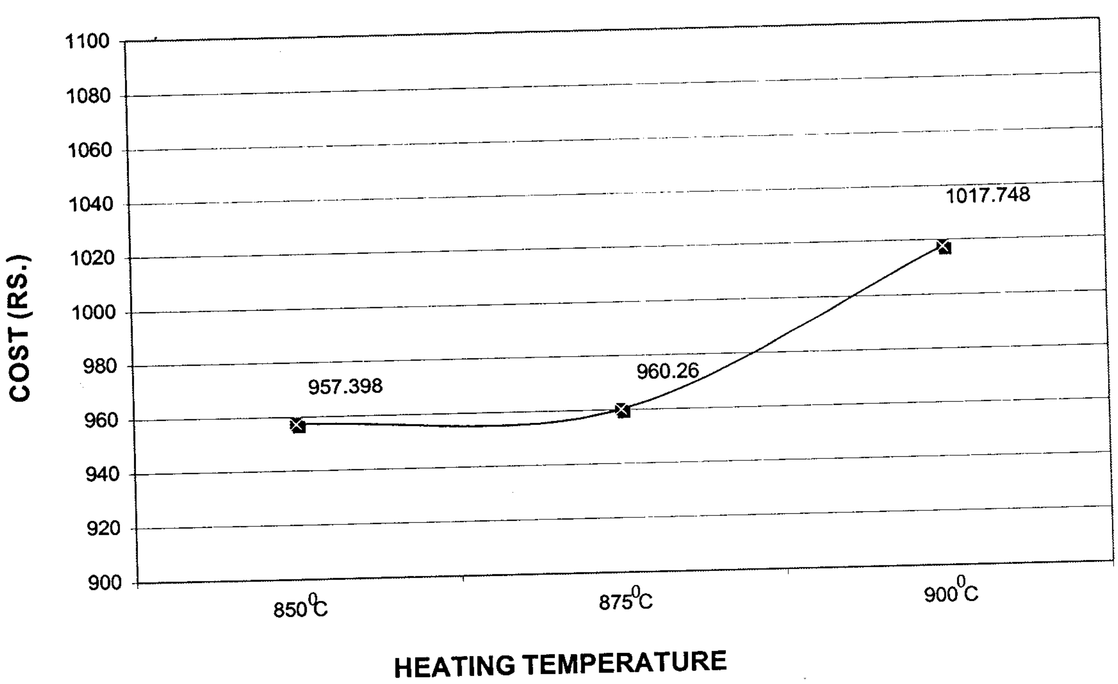


DIRECT EFFECT OF RATE OF COOLING ON COST





DIRECT EFFECT OF HEATING TEMPERATURE ON COST



Conclusion

Annealing

1. The optimum values of the process variables are found as follows.

   e. Rate of Heating = 150^0C / hour

   f. Rate of Cooling = 75^0C / hour

2. The Optimum Heat Treatment Cost is found as Rs. 1144.

3. For the Optimum Cost the Heat Treatment Time is calculated as 5 hours.

Normalising

1. The Optimum Values of the process variables are found as follows :

   a. Rate of Heating = 200^0C / hour

   b. Heating Temperature = 875^0C / hour

2. The Optimum Heat Treatment Cost is found as Rs. 750/-

3. For the Optimum Cost the Heat Treatment Time is calculated as 7 hours.

   These results, helps the organization to gain the following benefits :

   1. Heat treatment time in reduced.
   2. The cost involved in heat treatment, is reduced.
   3. The company can increase its productivity.
   4. Heat treatment quality can be retained.
   5. The company can quote competitive rates in attending tendors.

Suggestions for Improvement

Focus has been made in this project on motor body and compressor tank dished ends. In the same way, all other products which are heat treated, can be studied and optimum process variables can be obtained fro the products, so that the overall productivity of the company can be raised.

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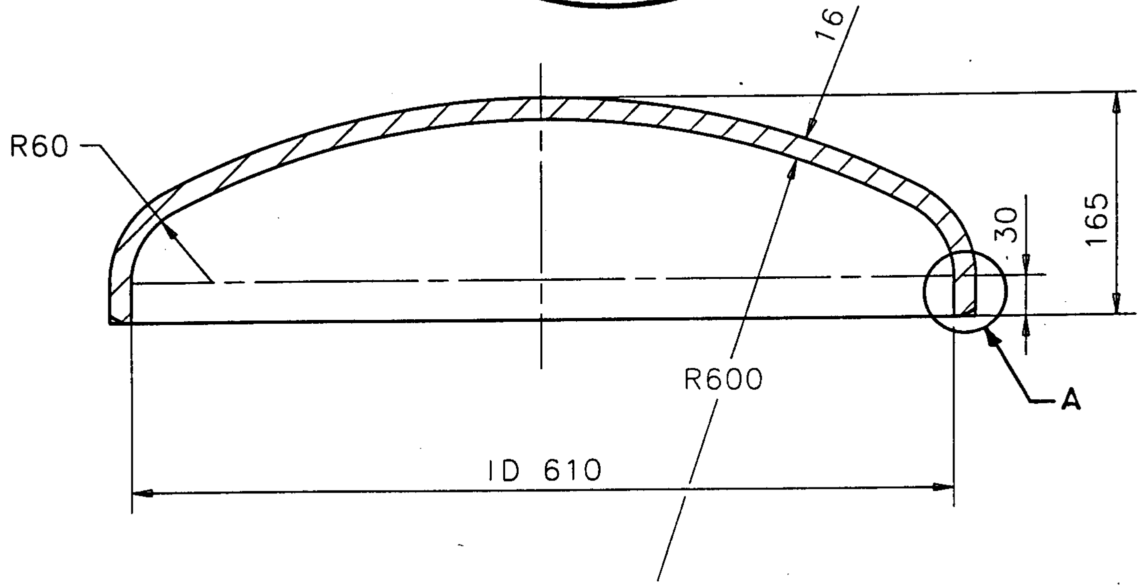
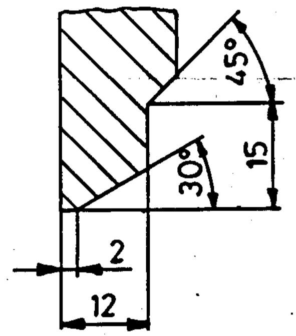
ALL DIMENSIONS ARE IN mm. UNLESS OTHERWISE SPECIFIED.

(2)

PROJ.NAME : VC - SERIES
FILE.NAME : 042400150

ELGI EQUIPMENTS LIMITED
ENGG DEPT.
22 NOV 1997
ISSUED BY:
H.O., COIMBATORE-18





Detail-A
Scale 1:1

BLANK DIA : ø800 X 16 THICK

WORKING PRESSURE : 30 kgf/cm2

22/11

DIMN.									
OVER	-	6	30	120	315	1000	2000	>4000
UP TO & INCL.	6	30	120	315	1000	2000	4000	
TOLERANCE	±0.1	±0.2	±0.3	±0.5	±0.8	±1.2	±2.0	±3.0

ROUGHNESS SYMBOL	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12
ROUGHNESS VALUE Ra um	0.025	0.05	0.1	0.2	0.4	0.8	1.6	3.2	6.3	12.5	25	50

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MODEL VC 00 014

MAT'L IS 2002 Gr.2

ELGI
ELGI EQUIPMENTS LTD
COIMBATORE - INDIA.

DISH, ID 610, THK 16

	NAME	DATE
DESIGNED		21/11
DRAWN		
CAD	KSK	21.11.97
CHECKED		21/11
APPROVED		Nov 21

RPF.DRG No.

NEXT ASSY.

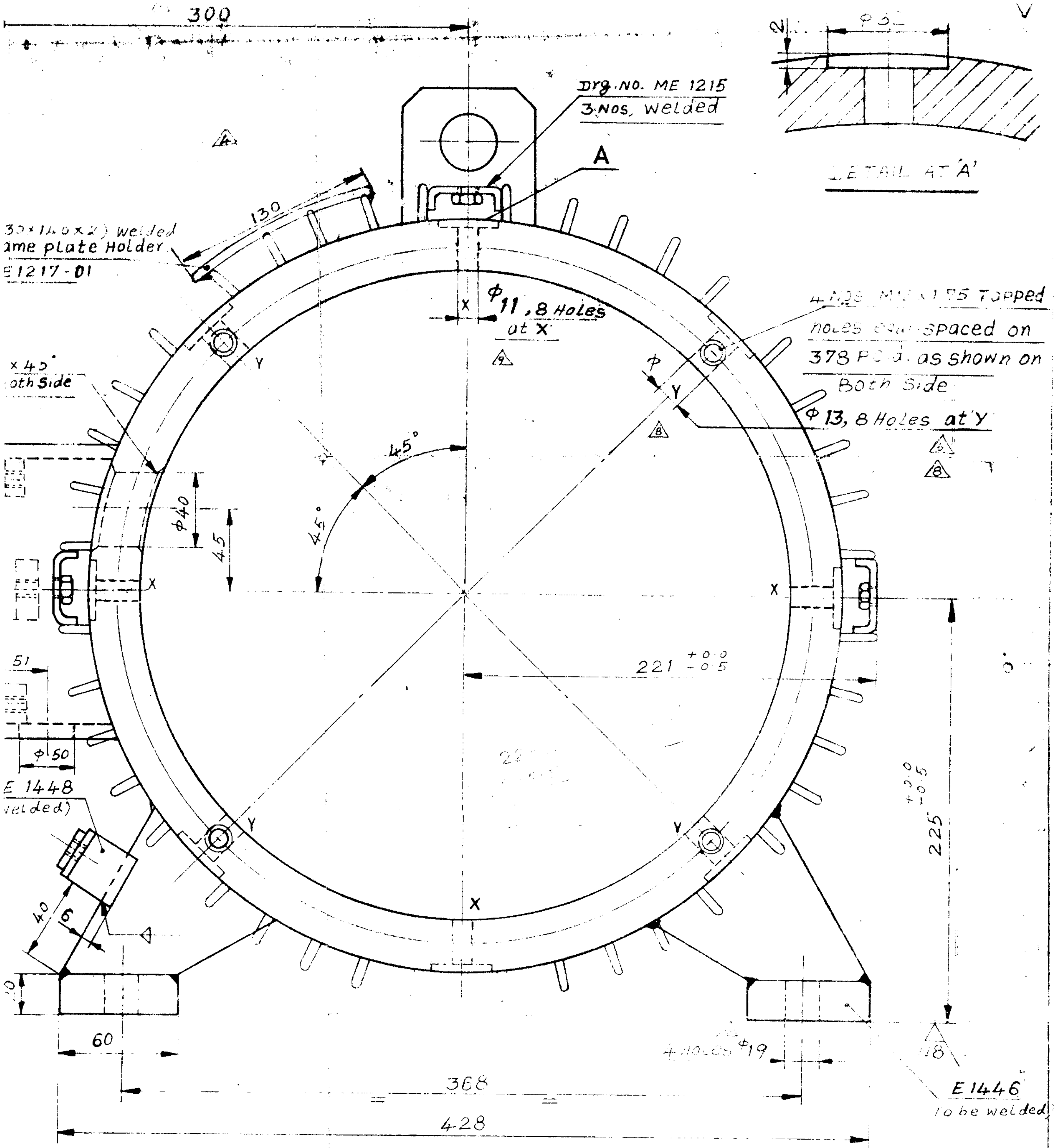
SCALE 1:5

DRG No. 04 24 0015 0

DRG.SHEET 1 OF 1

REVISION R00

DO NOT SCALE THIS DRAWING IF IN DOUBT ASK ENGG. DEPT.



OLE SHOE BORE $\phi 220^{+0.00}_{-0.20}$

REF No	ZONE	BRIEF RECORD	DATE
05	9	M12 Tap holes View Correction	
	8	ϕ13 is changed to 11ϕ	
04	5	ϕ11 is changed to ϕ13	
03	4	was 4 Nos M12 Tap holes	30/8/96
	Alt 933	ϕ220	
02	3	Pole Shoe Bore added	
		140 × 130 × 2	
	2	Name plat holder	
	1	Drawing Correction	22/6/96
		Terminal Box	
01		Changed. Was 230 dimn.	

Rev No	Zone	Brief Record	Sing; Date
07		was ϕ17	6/3/96
	9	ϕ 13, 8 Holes is changed to ϕ11, 8 Holes	
06	8	ϕ 11, 8 Holes is Changed to ϕ 13 8 Holes	23/11/96

NLESS OTHERWISE SPECIFIED.

11 11 100 22M'C

FMDC 225 M (Mark - 10)

TOLERANCE - IS 2102 (medium)

0.5/6	6/30	30/120	120/315	315/1000
±0.1	±0.2	±0.3	±0.5	±0.8

FESTO ELGI (P) LTD
INDIA HOUSE, TRICHY ROAD
COIMBATORE - 641018

MATERIAL STEEL IS:226

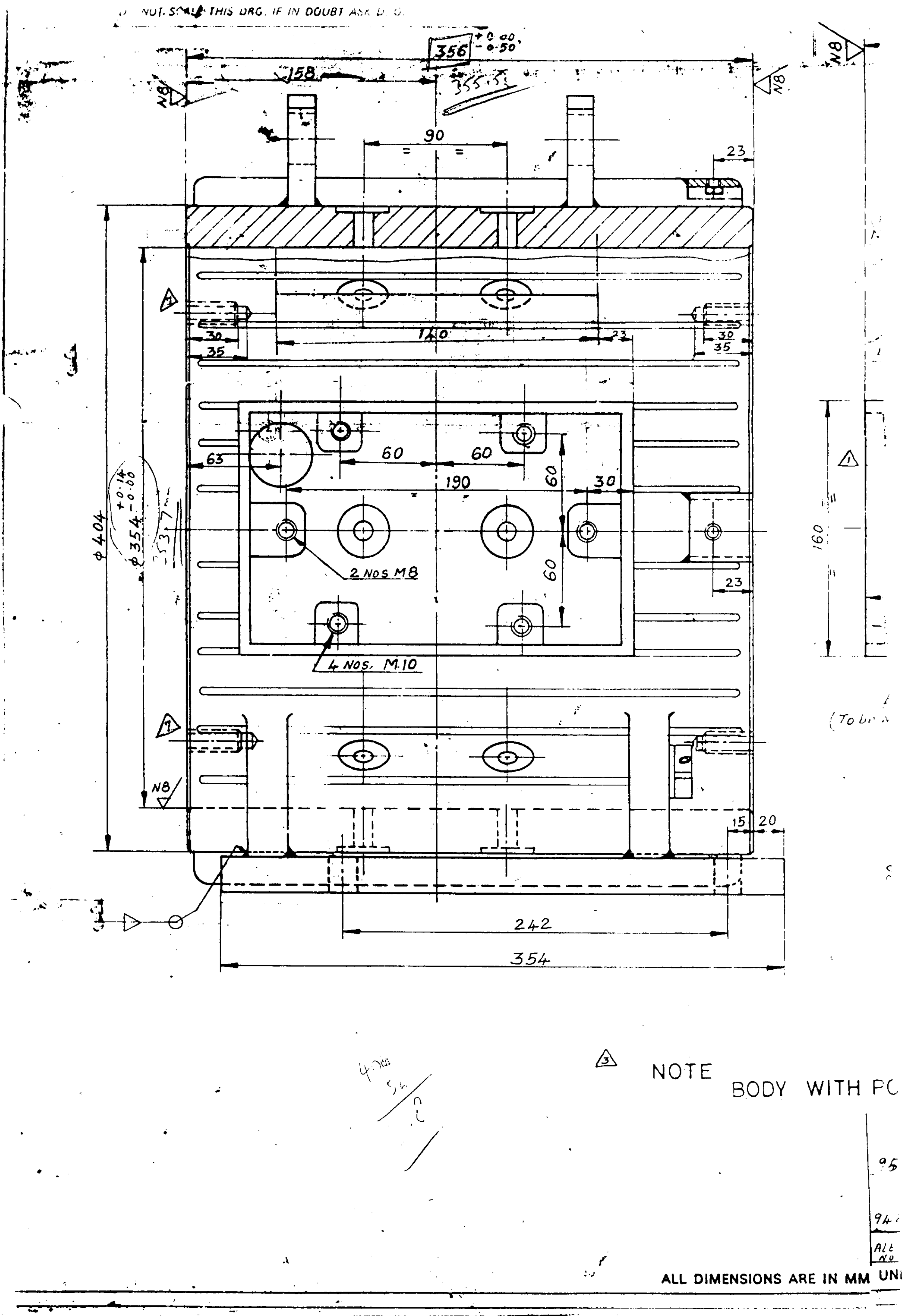
1988	NAME	DATE
DESIGNED		
DRAWN	MK Sridhar	29-11
CHECKED	MK Sridhar	25-6-96
STANDARD		
APPROVED		

SCALE 1:2

BODY WITH BASE

Machining Drg. (STRIP WOUND MOTOR)

DRAWING NO C1418-07


NOT SCALE THIS DRG. IF IN DOUBT ASK D.O.
356
+0.00
-0.50
158
N8
90
23
30
35
120
23
30
35
63
60
60
190
60
30
ϕ 404
ϕ 354
+0.14
-0.00
2 NOS M8
60
4 NOS. M.10
160
23
15
20
242
354
NOTE
BODY WITH PC
ALL DIMENSIONS ARE IN MM

CONVERSION OF HARDNESS NUMBERS AND THEIR CORRELATION WITH TENSILE STRENGH

Brinell Hardness Number		Rockwell Hardness Number Scale			Diamond pyramid hardness number	Shore cleroscope Hardness number	Tensile Strength N/mm^2
Impression ida, mm	Hardness Number	C	A	B			Carbon Steel
2.2	780	72	89	--	1224	--	--
2.25	745	70	87	--	1116	--	--
2.30	712	68	86	--	1022	--	--
2.35	627	66	85	--	941	90	--
2.40	653	64	84	--	868	86	--
2.45	627	62	83	--	804	84	--
2.55	578	58	81	--	694	78	--
2.60	555	56	79	--	649	75	--
2.65	534	54	78	--	606	71	--
2.70	514	52	77	--	587	69	--
2.75	495	50	76	--	551	66	1780
2.80	477	49	76	--	534	65	1720
2.85	461	48	75	--	502	64	1650
2.90	444	46	74	--	473	61	1600
2.95	429	45	73	--	460	59	1550
3.00	415	44	72	--	435	58	1490
3.02	409	43	72	--	423	57	1470
3.05	401	42	71	--	401	55	1395
3.10	388	41	71	--	401	55	1395
3.15	375	40	70	--	390	53	1350
3.20	363	39	70	--	380	52	1305
3.25	352	38	69	--	361	51	1265

CONVERSION OF HARDNESS NUMBERS AND THEIR CORRELATION WITH TENSILE STRENGH

Brinell Hardness Number		Rockwell Hardness Number Scale			Diamond pyramid hardness number	Shore cleroscope Hardness number	Tensile Strength N/mm^2
Impression ida, mm	Hardness Number	C	A	B			Carbon Steel
4.40	187	--	57	91	186	--	675
4.45	183	--	56	89	183	--	660
4.50	179	--	56	88	177	--	640
4.55	174	--	55	87	174	--	625
4.60	170	--	--	86	171	--	610
4.65	166	--	--	85	165	--	600
4.70	163	--	--	84	162	--	585
4.75	159	--	--	83	159	--	575
4.80	156	--	--	82	154	--	560
4.85	153	--	--	81	152	--	550
4.90	149	--	--	80	149	--	535
4.95	146	--	--	-78	147	--	525
5.00	143	--	--	-76	144	--	510
5.05	140	--	--	76	--	--	500
5.10	137	--	--	75	--	--	495
5.15	134	--	--	74	--	--	486
5.20	131	--	--	72	--	--	470
5.25	128	--	--	71	--	--	462
5.30	126	--	--	69	--	--	450
5.35	124	--	--	69	--	--	440
5.40	121	--	--	67	--	--	435
5.45	118	--	--	66	--	--	425

5.50	116	--	--	65	--	--	417
5.55	114	--	--	64	--	--	412
5.60	112	--	--	62	--	--	405
5.65	109	--	--	61	--	--	390
5.70	107	-	--	59	--	--	385
5.75	105	--	--	58	--	--	380
5.80	103	--	--	57	--	--	370
5.85	101	--	--	56	--	--	365
5.90	99	--	--	54	--	--	355
5.95	97	--	--	53	--	--	350
6.00	96	--	--	52	--	--	350
6.10	92	--	--	49.5	--	--	330
6.20	88	--	--	47	--	--	320
6.36	84	--	--	43.5	--	--	300
6.48	80	--	--	40.5	--	--	290
6.56	78	--	--	38.5	--	--	280

APPROXIMATE HEATING TIME FOR STEELS IN VARIOUS TYPES OF FURNACES

	Furnace Temp/0C	Heating time per mm dia or thickness of article, see		
		Round section	Square Section	Rectangular Section
Electric Furnace	800	40-50	50-60	60-75
Oil Furnace	800	35-40	45-50	55-60
Salt Bath	800	12-15	15-18	18-22
Lead Bath	800	6-8	8-10	10-12
Salt Bath	1300	6-8	8-10	10-12