Liquid-Liquid Extraction of Metal Ions Using Aqueous Biphasic Systems

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Abstract

An investigation was conducted for the study of extraction of metal ions using aqueous biphasic systems. The extraction of iron, zinc and copper from aqueous sulphate media at different kinds of extractants SCN^-, Cl^- and I^-, different values of pH of the feed solution, phase ratio, concentration of metals, concentration of extractant, concentration of polymer, and concentration of salt was investigated. Atomic absorption spectrophotometer was used to measure the concentration of iron, zinc and copper in the aqueous phase throughout the experiments. The results of the extraction experiments showed the use of SCN^- as extractant, pH=2.5, phase ratio=1.5, concentration of metals 1g/l, concentration of extractant 0.06 %, concentration of polymer =50 %, and concentration of salt=20% gave the highest value of percent removed. Also increase of extractant concentration increases the percent removed. The results clarified that increasing the metal ions concentration in the aqueous phase causes to decease the percent removed. The addition of an inorganic salt (sodium sulphate) up to (20%) increased the dehydration of polymer chains and then increases the percent removed.

الخلاصة

تم في هذا البحث دراسة عملية استخلاص ايونات المعادن من محاليها المائية باستخدام انظمة الطورين المائية. تتضمن الدراسة استخلاص ايونات الحديد،الزنك والنحاس من وسط محلول كبريتي تحت ظروف مختلفة وهي: نوع المذيب SCN^-,Cl^-,I^- ، pH المحلول ،نسبة الطور،تركيز المعادن تركيز المذيب المستخدم ، تركيز البوليمر ،وتركيز الملح .

تم تحليل النتائج باستخدام جهاز الامتصاص الذري ،واظهرت التجارب ان استخدام (SCN^-) كمذيب وpH (2.5) ونسبة الطور (1.5) وتركيز المعادن (1 غم /لتر) وتركيز المذيب (0.06 % حجما) وتركيز البوليمر (50 % وزنا) وتركيز الملح (20 %) تعطي اعلى قيمة لنسبة الازالة للمعادن، كذلك بزيادة تركيز المذيب يزداد معامل الاستخلاص وان زيادة تركيز ايونات المعادن في المحلول المائي تسبب نقصان في معامل الاستخلاص .ان اضافة الملح غير العضوي (كبريتات الصوديوم) لغاية 20 % تسبب زيادة لنسبة الازالة.

Introduction

Traditional solvent extraction is one of the most useful techniques that are being used for selective removal and recovery of metal ions from aqueous solutions and it is largely applied in the purification processes in numerous chemical and metallurgical industries [Dean J.R.1998].

In liquid-liquid extraction system, water immiscible and miscible solvents are employed. Cationic or anionic forms of metals are complexed into an organophilic compounds or an ion-pairs by chelation or using ion-pairing agents. If the water immiscible solvent and an aqueous solution containing a hydrophobic species are brought into contact, the chelate or an ion-pair is transferred into the organic phase [Thurman E. M. and Mills M.S.1998].

Advantages of liquid-liquid extraction are simplicity and rapidity. The solvents are not highly flammable and easily recoverable. They are stable, transparent to UV, not emulsifying during extraction as selective as possible. Disadvantages of liquid-liquid extraction methods are emulsion formation, different extraction efficiencies for various compounds with various extracting agents, and low sensitivity. In these processes, metal ion containing solution contacts with a large amount of selective solvent. After extraction, stripping follows this process. Solvent extraction is very difficult for the separation of quantitatively of metal ions because of low driving force, and then a large amount of solvent is required. These make the extraction and stripping of desired species very expensive [Triangl P.1983].

Even with today's environmental standards a number of extraction systems still utilize toxic and flammable organic diluents. When the diluent is coupled with a highly selective extractant the cost of the solvent system can become very expensive [Walter H. and Johansson G.1994].

The goal of Technology is to enable the (chemical) industry to continue to lead in technology development, manufacturing and profitability, while optimizing health and safety and ensuring environmental stewardship. New separations technologies developed for pollution prevention may also find application in pollution remediation, helping to clean up already contaminated sites. Aqueous biphasic systems (ABS) consist of two immiscible phases formed when certain water-soluble polymers are combined with one another or with certain inorganic salts in specific concentrations. As two-phase systems they are suitable for carrying out liquid-liquid separations of various solutes such as biomolecules, metal ions, and particulates. In ABS the major component in each of the two phases is water, and because of this non-denaturing environment these systems have been widely employed in biological separations for over 40 years [Rogers R.D. and Eitema M.A.1995].There are three kinds of (ABS): polymer–polymer systems, polymer-salt systems, and more recently salt-salt systems. The literature has reported equilibrium data for different (ABS) formed by poly ethylene glycol (PEG) of different average molar masses and inorganic salt [Bridges N.J. at.el.2007].

Separation processes are applied in various types of industries including chemical, pharmaceutical, and food. Classic methods involving liquid-liquid extraction use an organic solvent and an aqueous solution as the two immiscible phases for the fractionation and purification of molecules. However, these systems are very toxic and present risks to human health. An alternative to substitute organic two-phase systems, based on the beginning of green chemistry, is aqueous biphasic systems (ABS). They are formed by the mixture of a polymer + water + salt or two water-soluble polymers differing in chemical structure. This methodology has been widely used to separate metallic ions and biological materials such as viruses, nucleic acids, and proteins. These characteristics are important because an organic solvent is not used in the separation processes [Martins J. at.el.2008].

Experimental

Materials

The PEG used in this study was PEG-3000 (average molecular mass = 3000). Stock solutions of 10%, 20%, 30% and 40% (w/w) PEG were prepared by dissolving of suitable quantity of PEG in deionized water. The stock solution of inorganic salt (Na_2SO_4) (5%, 10%, 15% and 20% (w/w) Na_2SO_4) was prepared by dissolving in deionized water. The solution of metal ions was prepared by dissolving $CuSO_4$, Fe_2SO_4 and $ZnSO_4$ in deionized water to reach the required concentration of metal of about (1g/l) for each metal. The extractant used was prepared by dissolving KI, KCl, and KSCN in deionized water to reach the extractant ions. The different pH values were obtained by adding small volumes of acid (H_2SO_4) or base (NaOH) concentrated solutions, which were considered in the total solution mass.

Methods

Aqueous two-phase system was prepared by mixing equal volumes (20 ml) of PEG stock solution and inorganic salt stock solutions (20%w/w),The other variable were pH (2),metal concentration (1g/l), extractant concentration (0.05%), polymer concentration (40%) and salt concentration (20%).The effect of extractant type on the percent removed was investigated by use KI, KCl, and KSCN. The system was mixed for (15 minute) followed by (10 minute) of Centrifugation at (2000 rpm). Just before analysis, the two immiscible phases were carefully separated with Pasteur pipettes and placed into separated tubes. Equal volumes (1ml) for each phase were measured for ZN (II), CU (II), and Fe (III) by means of atomic absorption spectrophotometer model (AA-670, Shimadzu corporation, Japan).Phase ratio (PEG/ Na_2SO_4) was studied for the mixtures which had the best percent removed of the metals with (0.5, 1,1.5,2,2.5 and 3) (Polymer /inorganic salt ratio).Study the effect other variable on percent removed, different pH values (1, 1.5, 2, 2.5, 3, 3.5 and 4),concentration of metals (0.5-3g/l),concentration of extractant (0.01-0.06 extractant vol. / salt vol. %),concentration of polymer (10-50 %) and finally concentration of salt (5-20 %).

Results and Discussion

Effect of Extractant Type

The effect of extractant type on the percent removed was investigated. The operating conditions were (pH = 2, metal concentration = 1g/l, phase ratio =1, extractant concentration =0.05%, polymer concentration = 40% and salt concentration=20%) being kept constant.

The results obtained from this set are listed in Table1, showing that using thiocyanate as an extractant give the highest

value of percent removed. The distribution behavior of Fe (III), Cu (II), and Zn (II) was studied in an aqueous two-phase system formed from a polyethylene glycol and sodium sulphate in the presence of thiocyanate, chloride, and iodide ions. From the distribution ratios determined as a function of the iodide, chloride or thiocyanate concentration. In the SCN^- system Cu(II), Zn(II) distribute into the PEG-rich phase predominantly as $Cu(SCN)_4^{-2}$, $Zn(SCN)_4^{-2}$ and Fe(III) as $Fe(SCN)_4^-$, respectively. The extractabilities of the metal ions depend not only on the stabilities of the metal thiocyanate, chloride or iodide complexes but also on those of their sulphate complexes.This is presumably due to the difference in the stability constant between the thiocyanate complex and the iodide or chloride. It has also been suggested that the extractability of a metal ion with complexing anions in aqueous two-phase systems formed by a polymer and an inorganic salt depends not only on the complexing ability of the extracting anions but also that of the anion of the phase-forming salt [Masami Shibukawa at.el. 2001].

Effect The pH of The Solution

The effect of pH solution on the percent removal was investigated. Keeping other variables constant (metal concentration = 1g/l, phase ratio =1,extractant concentration =0.05% ,polymer concentration= 40% and salt concentration=20%).The results as shown in Fig.(1) indicate that increasing the pH lead to an increase in the percent removed up to a limit then decreases. Thus, pH =2.5 gave the highest value of percentage of metals removal. The decrease in recovery beyond pH=2.5 is due to hydrolysis of the metal. This might be attributed to a reveres action due to unstable complex formation between the

metal species and the thiocyanate which will lead to a reduction in the percent removed. In general, decreasing the pH of the salt stock solution has the effect of increasing the hydrophobicity of the PEG-rich phase and, thus, enhancement of the efficiency of metal ion extraction increases with increasing acidity of the salt stock solution [Bulgariu L. and Bulgariu D. 2007] and [Bulgariu L. and Bulgariu D. 2008].

Effect of Phase Ratio

The effect of phase ratio on the percent removed was investigated. From the previous section pH (2.5) is used at this set. Keeping other variables constant (metal concentration = 1g/l, extractant concentration =0.05%, polymer concentration = 40% and salt concentration=20%).The results obtained showed that phase ratio of (1.5) gave the highest value for the system as indicated in Fig. (2), this may be attributed to the large difference in the concentration of the two phase systems, so that the solute extraction is increased because of the solute hydration . Further support the above conclusion where this figure represent the percentage removal of metals (Fe=66.25, Zn=75.99 and Cu=85.25), the percentage of metals removal increases up to a limit then it remains nearly constant. The behavior because when the concentration of the PEG polymer is increased the stronger hydrogen bonding between the PEG molecules and the water is increased, causing raise in the cloud point (the interface between the two phase systems) [Rogers R.D. and Eitema M.A.1995].

Effect of The Metals Concentration

The effect of metals concentration on the percent removed was investigated. From the results of previous sections as it were noticed, pH (2.5) and phase ratio (1.5) gave the highest percent removed. These conditions were used in this section. Keeping other variables constant (extractant concentration =0.05%, polymer concentration = 40% and salt concentration=20%). Increasing the metals concentration in the feed, the extraction percentage of metal removed decrease. These results could clearly be seen in Fig. (3), the formation of an extractant-metal complexing in the PEG will produce a lower concentration of free extractant. A certain number of extraction molecules associated with each metal ion, thus upon keeping other variable constant, the concentration in the solvent will remain almost constant in spite of its increase in the aqueous phase [Bulgariu L. and Bulgariu D. 2007].

Effect of The Extractant Concentration

The effect of extractant concentration on the percent removed was investigated. From the results of previous sections as it were noticed, pH (2.5), phase ratio (1.5) and metal concentration (1g/l) gave the highest percent removed. These conditions were used these experiments. Keeping other variables constant (polymer concentration = 40% and salt concentration =20%).Percentage of metal removed plotted vs. extractant concentration in the Fig. (4) Showed that upon increasing the extractant concentration, the percentage of metals removed increased and the best values were (Fe=69.61, Zn=77.35 and

Cu=89.23).This is due to the polar nature of the extractant, which might cause an interaction between the extractant and the metal. Thus, the formation of an extractant-metal complexing in the PEG will produce a lower concentration of free extractant.

Effect of the Poly Ethylene Glycol Concentration(PEG)

The effect of the poly ethylene glycol concentration on the percent removed was investigated. Wide range of the extraction coefficient values was obtained using different poly ethylene glycol concentration. Fig. (5) Shows that increasing poly ethylene glycol concentrations increase the values of percentage of metals removal (Fe=70.71, Zn=81.25 and Cu=91.42).

The metal ion, initially present in salt-rich phase as anionic or neutral species will interact with inorganic extractants, most probably at interface, and the formed species will be then partitioned into PEG rich phase. In our opinion, the formation of extractable species occurs step by step, until his hydration degree becomes comparable with the hydration environment of PEG-rich phase from extraction system [Bulgariu L. and Bulgariu D. 2007]

Effect of Salt Concentration (Na_2SO_4)

The effect of salt concentration on the percent removed was investigated .The results obtained shows that salt concentration (20%) gave the highest value for the system as indicated in Fig.(6) the percentage of metal removal increases as the salt percent increases (Fe=70.71%, Zn=81.25% and Cu=91.42%).

The formation of aqueous two-phase system of PEG and a certain inorganic salt

can be explained on the basis of the competition for hydration between the two components. The addition of an inorganic salt increases the dehydration of the polymer chains, due to the salting-out effect and phase separation. Thus, two immiscible aqueous phases are obtained: an upper one – rich in PEG, having the same role as the organic phase in traditional extraction systems, and a lower one, rich in the inorganic salt [Bulgariu L. and Bulgariu D. 2008].

Conclusions

1. It was found that (SCN^-) ion is more active extractant than Cl^- and I^- ions for extraction of metal ions.
2. The results indicate that increasing the pH of the solution lead to increase the percent removal of the metal ions up to about 2.5 then decrease ,and the phase ratio of (1.5) gave the highest percent removal of metal ions
3. The results showed that and on increasing the metals concentration in the feed, the percentage of metal removed decreases.
4. The results indicate that the percent removal of metal ions increases with increasing the extractant concentration, increasing of poly ethylene glycol concentrations and addition of an inorganic salt
5. Two immiscible aqueous phases are obtained: an upper one – rich in PEG, having the same role as the organic phase in traditional extraction systems, and a lower one, rich in the inorganic salt.

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Walter H.; Johansson G., Aqueous Two-Phase Systems; In Methods in Enzymology; Academic Press: San Diego, 1994; Vol. 228.

Table (1) Effect of Extractant Type

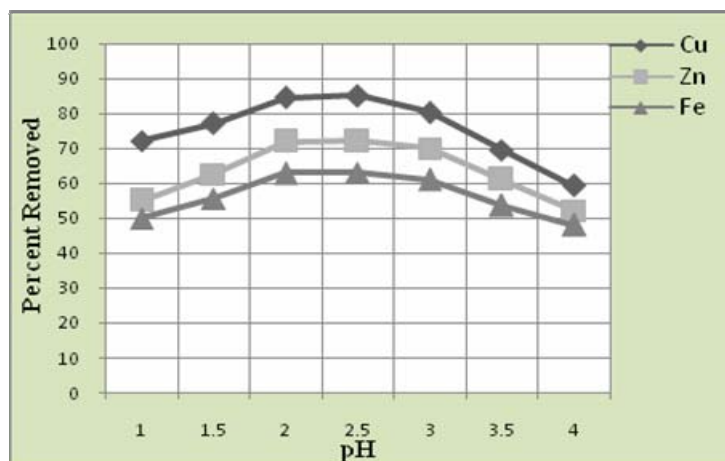| Extractant	%Removed Fe.	%Removed Zn.	%Removed Cu.
SCN^-	63.12	72.23	84.77
Cl^-	48.32	51.22	57.46
I^-	8.19	9.18	49.44

Figure 1: Percent removed vs. pH of the solution, at phase ratio =1, metal concentration =1g/l, extractant concentration =0.05%, polymer concentration = 40% and salt concentration=20%.
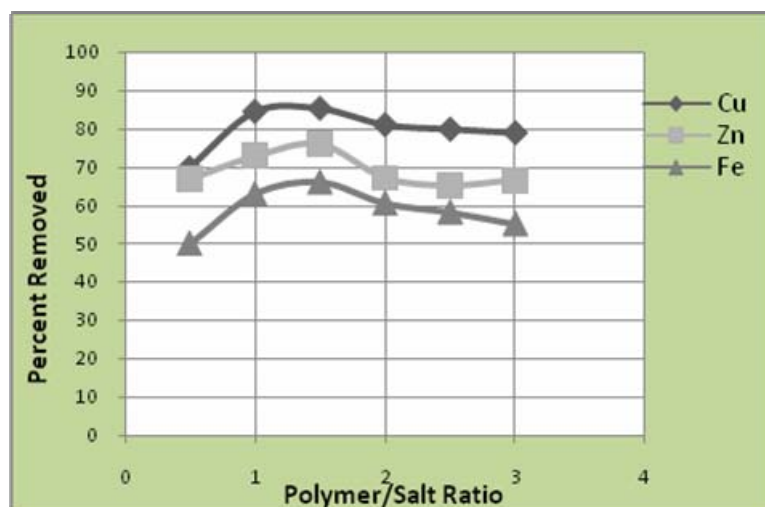
Figure 2 Percent removed vs. phase ratio, pH=2.5, metal concentration=1g/l, extractant concentration =0.05%, polymer concentration=40% and salt concentration = 20 %.
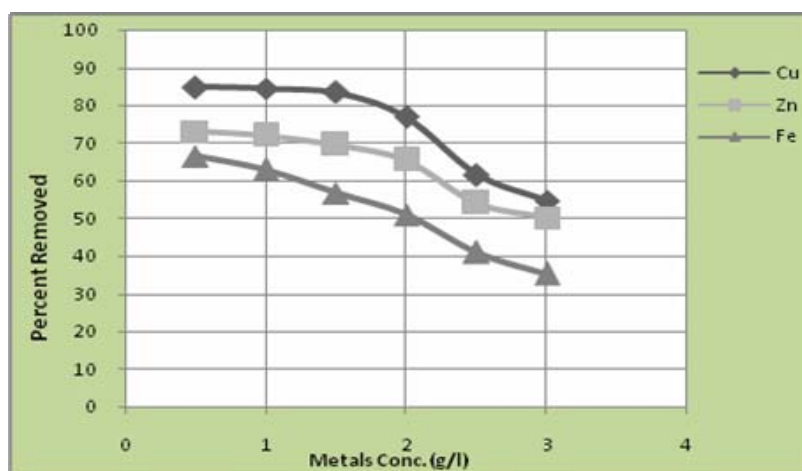

Figure 3 Percent removed vs. metal concentration in the feed, at pH=2.5, phase ratio=1.5, extractant concentration=0.05%, polymer concentration=40% and salt concentration=20%.
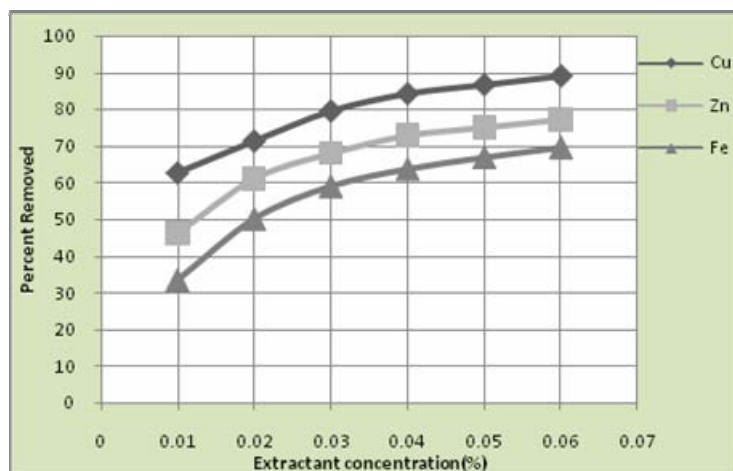
Figure 4 Percent removed vs. extractant concentration, at pH=2.5, phase ratio =1.5, metal concentration = 1g/l, polymer concentration = 40% and salt concentration=20%.
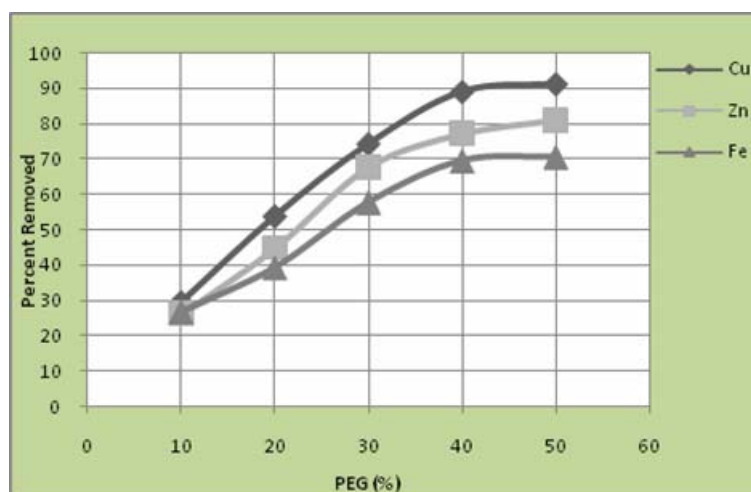

Figure 5 Percent removed vs. polymer concentration, at pH=2.5, phase ratio =1.5, metal concentration =1g/l, extractant concentration =0.06%and salt concentration=20%.
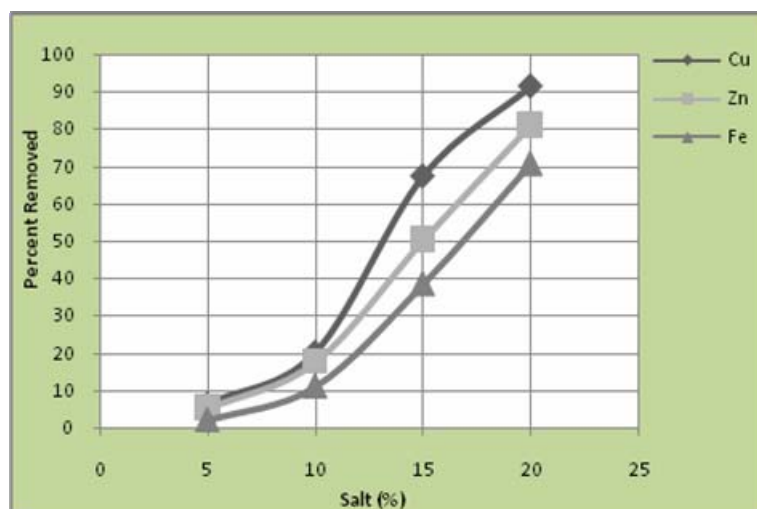
Figure 6 Percent removed vs. salt concentration, at pH=2.5, phase ratio =1.5, metal concentration =1g/l, extractant concentration=0.06% and polymer concentration =50%.

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المجمعات السكنية المصممة بوصفها بديلا عن البناء العشوائي واثرها
في معالجة عدم التجانس في المشهد الحضري للمناطق السكنية المشيدة

The designed housing projects as an alternative for the informal building and their impact in addressing the heterogeneity of the urban escape in the built residential areas

Dr.Wahda Shukur Al-Hinkawi   Dr.safaa Aldeen Ali   Dr.Anwar Subhi Al-Qaraghuli

Abstract
     The   phenomenon of informal building Spread recently in Iraqi residential areas, in general, and in Baghdad, in particular, due to the urgent housing need, on the one hand, and lack of commitment to building controls, on the other hand, **to highlight the phenomenon of uncommitted building to controls and housing governing legislation in Iraq**, leading to heterogeneity in both building densities and plot areas, and disorder in the urban fabric and urban escape of those areas.

     Research problem identified as the **absence of a clear vision about the General aspects of the phenomenon of informal building in residential street scene, and the role of designed housing projects as a substitute for informal building in built residential areas.**

     The designed housing projects (single or multi story buildings), which designed and constructed accordance to the approved planning and construction regulations and legislation, as one of the solution to the housing crisis, that achieve the harmonious at each level of the urban fabric and urban escape. Accordingly the research hypothesis stated as **"the designed housing projects achieve homogeneous formal unity in residential street scene".**

     This paper deals with the role of designed residential projects to reduce the phenomenon of informal building and heterogeneity in the urban escape of built residential areas, by identifying the phenomenon in residential areas, in general, and in selected area in Baghdad, in particular, first, and present a designed housing projects (global and local) that achieve homogeneous formal unity at the level of the urban escape, second, the research identified the principles and the elements of the residential street scene and the organization bases that can be a substitute for the informal building and the heterogeneity of the urban escape in built residential areas, third.

Key words:
Informal building, informal housing, urban escape, residential street scene, designed housing projects.

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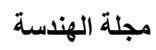• :   –

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**جدول رقم (1): الجوانب العامة لظاهرة البناء والسكن العشوائي/ المصدر: الباحثون**

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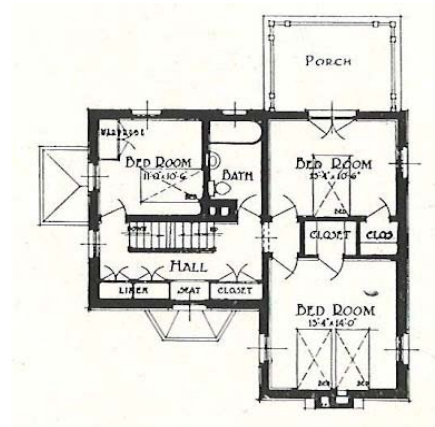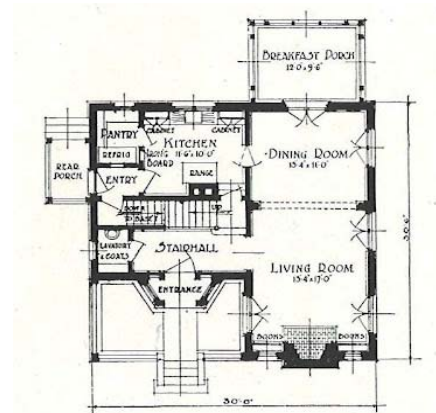
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ا.م.د. وحدة شكر محمود الحنكاوي
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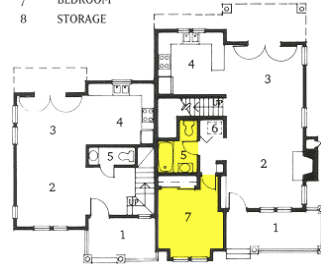في معالجة عدم التجانس في المشهد الحضري للمناطق السكنية المشيدة

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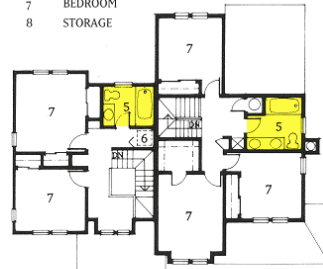في معالجة عدم التجانس في المشهد الحضري للمناطق السكنية المشيدة

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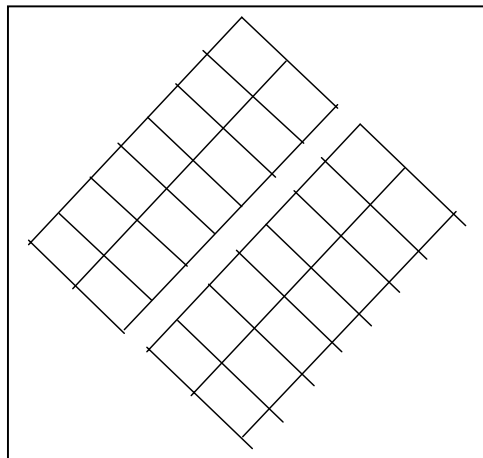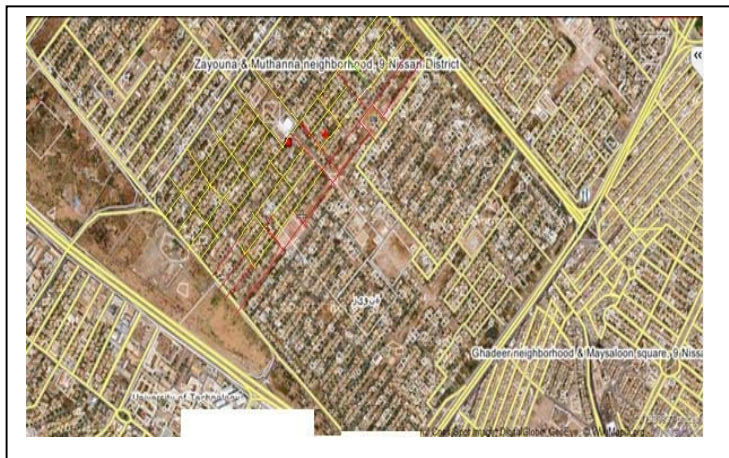
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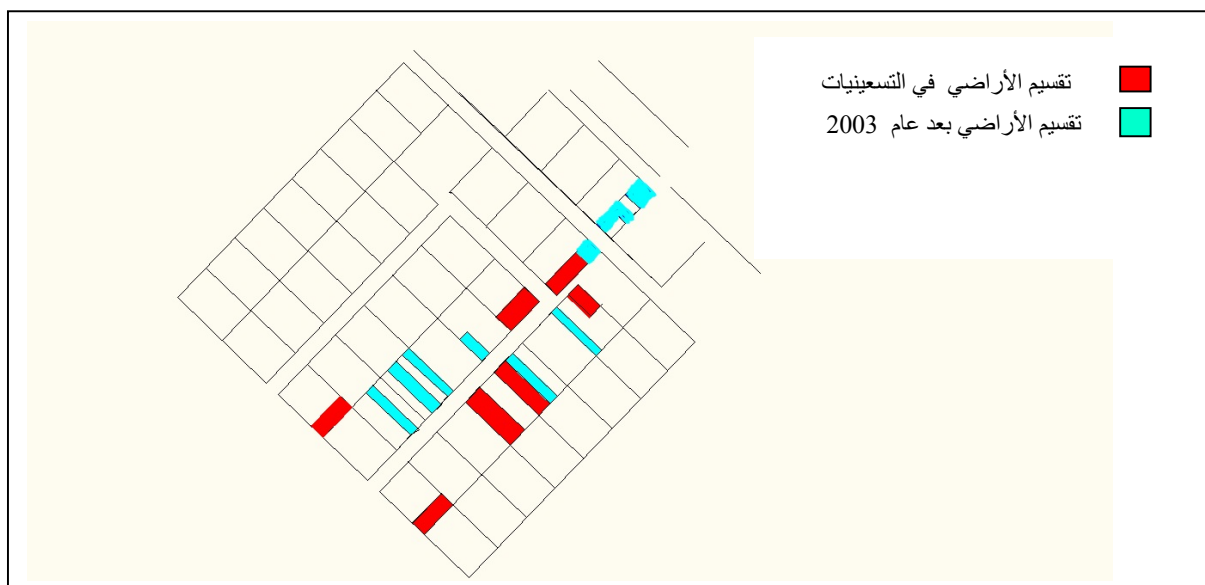
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صورة رقم 3
وحدات سكنية صغيرة غير مرخصة

صورة رقم 4
اضافة فضاءات تجارية الى المساكن المشيدة

صورة رقم 5
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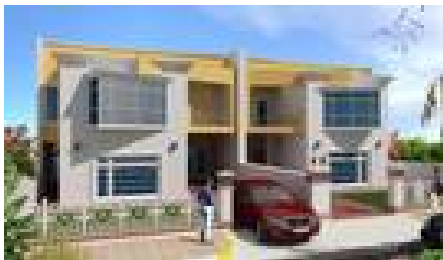في معالجة عدم التجانس في المشهد الحضري للمناطق السكنية المشيدة

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FRONT PORCH
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DINING ROOM
KITCHEN
BATH
WASHER/DRYER
BEDROOM
STORAGE

First floor plan

2 bedroom and 4 bedroom floor plans

FRONT PORCH
LIVING ROOM
DINING ROOM
KITCHEN
BATH
WASHER/DRYER
BEDROOM
STORAGE

Second floor plan

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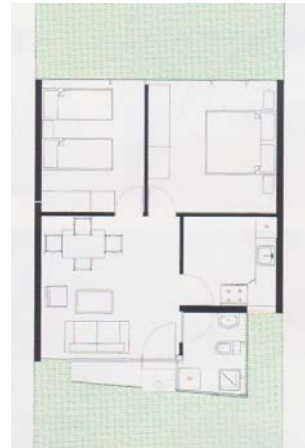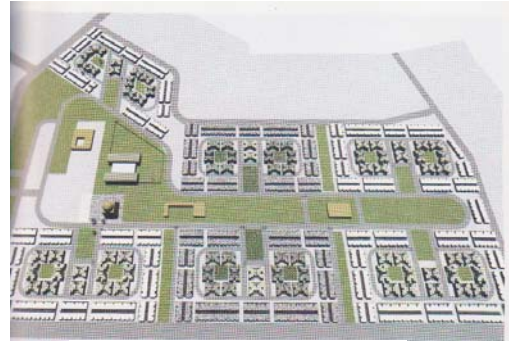
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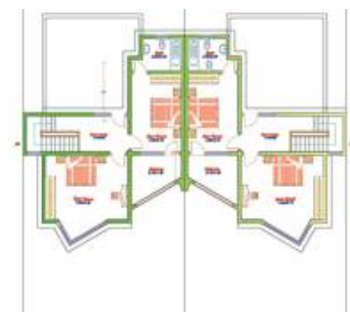
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Development of an Integrated Construction Management System for Building Estimation

Assist. Prof. Dr. Sawsan Rasheed Mohammed

Ehab Fadhil Mohammed Ali

Abstract

Project management are still depending on manual exchange of information based on paper documents. Where design drawings drafting by computer-aided design (CAD), but the data needed by project management software can not be extracted directly from CAD, and must be manually entered by the user. The process of calculation and collection of information from drawings and enter in the project management software needs effort and time with the possibility of errors in the transfer and enter of information. This research presents an integrated computer system for building projects where the extraction and import quantities, through the interpretation of AutoCAD drawing with MS Access database of unit costs and productivities for the pricing and duration of tasks, then exported to MS Project and MS Excel. The system was developed by using Visual Basic and ActiveX automation technology for combining the above software. The system, also, can calculate quantities of materials. The system includes digitizer (on-screen takeoff) calculates the lengths and areas of the drawings to which the form of an image and scanned. The integrated system has been applied to case study, a storages building for hospital 260 beds. The results proved the effectiveness of the system for the conversion of information from the graphical form *dwg* to numerical formulas *xlcx / xlc* and *mpp* can be handled easily pleased and software are covered.

Keywords: Construction Management, Integrated System, CAD, Estimation, Automation

الخلاصة

لا تزال إدارة المشاريع تعتمد التبادل اليدوي للمعلومات و بالاستناد على الوثائق الورقية. حيث يتم رسم الخرائط و المخططات التصميمية بمساعدة الحاسوب CAD, لكن البيانات المطلوب ادخالها لبرامجيات إدارة المشاريع لا يمكن استخراجها مباشرة من CAD بل يجب ادخالها يدويا من قبل المستخدم. ان عملية أخذ و تجميع المعلومات من المخططات التصميمة و ادخالها في برامجيات ادارة المشاريع تحتاج الى جهد و وقت مع احتمال حدوث اخطاء في نقل و ادخال المعلومات. هذا البحث يقدم نظاما حاسوبيا متكاملا لمشاريع المباني حيث يقوم باستخلاص و استيراد الكميات عن طريق ترجمة مخططات AutoCAD مع قاعدة بيانات MS Access بالكلف و الانتاجيات لحساب الاسعار و المدد الزمنية للفعاليات ثم تصديرها الى برامج MS Project و MS Excel. تم تطوير النظام بأستخدام Visual Basic و تقنية أتمتة ActiveX لربط البرامج اعلاه. بالاضافة الى حساب كميات المواد ، يتضمن النظام Digitizer لحساب الاطوال و المساحات للمخططات التي تكون بصيغة صورية. تم تطبيق النظام المتكامل على دراسة حالة لبناية مخازن لمستشفى 260 سرير. اثبتت النتائج فعالية النظام في تحويل المعلومات من صيغتها الرسومية dwg الى صيغ عددية xlcx / xlc، mpp يمكن التعامل معها بسهولة و يسر بالبرامجيات المشمولة بها.

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Development of an Integrated Construction
Management System for Building Estimation

Introduction

In each phase of project life cycle a lot of information is exchanged among project teams. This information can be graphical (drawings) or non-graphical information (bill of quantities). These two information as independent and are not linked to each other. Current estimating is limited by the lack of integration between electronic design and construction information. Integration of design and cost information is necessary to improve the estimating and to reduce the current fragmentation. New software technologies have been developed that will help to integrate design and cost information (Staub et al, 1998).

In USA, (Elzarka, 2001) had discussed a cost-effective approach for developing computer-integrated construction (CIC) systems by integrating stand-alone CAD (AutoCAD), spreadsheet (Excel), database (MS Access) and scheduling software (MS Project) packages using Visual Basic and ActiveX technology. In India, (Arun and Appa Rao, 2005) presented a simple methodology for integrating computer aided design with construction scheduling using Visual Basic and ActiveX. It makes use of the widely used standard software application packages namely AutoCAD and MS Project along with MS Access database. The integration was achieved by developing suitable interfacing modules and also by creating the knowledge based expert system for incorporating the construction expertise to be used for achieving integration.

In Iraq, Only (Ziyad, 2007) have been developed integrated system CIS (Computer Integrated System) for water Projects, to connect three software (AutoCAD, Excel and MS Project) using Visual Basic and ActiveX data transfer technology. This integrated system can extract the graphical information from an AutoCAD drawing and transfer it to a digital form suitable for processing in the project management software MS Excel and MS

Project Due to the CIS does not have a database; unit cost, production rate, precedence of the activities should be entered by user. Passing information from AutoCAD to MS Project indirect, should be presenting it in Excel first. Measure only lengths and quantities that calculate by each, without area and volume.

Research Objectives

The aim of this research is to present a simple approach for integrating CAD with estimation and planning, and to apply it for the case of building projects, as an example. It presents an approach for integrating the existing software. The integration of stand-alone AutoCAD, MS Access, MS Excel and MS Project by using Visual Basic and ActiveX automation technology was proposed as an alternative approach to developing integrated system (InCADEP).

Software Applications in Construction

Computer Aided Design

Before the 1980s, most drawings were created using paper. In 1982, Autodesk introduced AutoCAD software, bringing CAD to the PC and changing the design world forever.

Its use however has been limited to drafting for so many years that it is sometimes referred to as "Computer-Aided Drafting" (Elzarka and Dorsey, 1999). The development of IT and its application in construction industry have brought about some changes to the industry. Such as, the application of CAD grants a CAD drawing with two meanings (Wang, 2001):

- To engineers, it consists of a series of graphic symbols representing a building;
- To computer, it is a process-able data file which contains data related to the building, and this makes it possible to interpret the CAD

drawing and to extract from it the data needed for construction management.

Estimating Software

The computation of construction quantities is one of those tasks which can be dealt with computer technologies. Generally, computing by hands or by evaluation computer software are two major methods for quantity calculation. There are few disadvantages with performing these two methods (Lin, 2007):

- Time consuming.
- Accumulative errors and typos produced from manually computing.
- Leaving some area out of consideration.
- Personnel's lack of graphic working experience to perform the calculation jobs.
- Original system limitations, such as format of input data, etc.

The accuracy of construction quantity is one of the most important factors for controlling building cost in construction industry (Lin, 2007).

The fundamental core of estimating is the takeoff process. Without the information obtained from a takeoff, an estimate can not be performed. While the level of detail varies, the need to know the information obtained in the takeoff process is still vital (Miller, 2001). In the takeoff phase, computer based systems have dramatically changed the available tools from pencils and papers to interactive digitizers (Elzarka and Dorsey, 1999). A simple digitizer was included in the presented system in this research.

In the pricing phase, where prices are assigned to the items selected during takeoff, computer based system have had a major impact. The database of these systems contains most of the pertinent information necessary to prepare an estimate such as unit price and

production rate. Such information needs to be entered only once into the database, where it is stored for future use (Elzarka and Dorsey, 1999).

Spreadsheets

Large construction companies use estimating software that cost thousands or even tens of thousands of dollars to purchase (more money than most small-to-medium size builders can afford). However, there are inexpensive ways to do computer estimating. One way is to use computerized spreadsheets that have the power of programs costing thousands of dollars. The benefits of having computer spreadsheets are (Christofferson, 1999):

- Inexpensive
- Easy to use
- Can be customized to your style of doing business
- Very powerful.

(Christofferson, 1999) provides some helpful methods that can turn basic spreadsheets into powerful tools to accomplish estimates quickly and accurately. But main limitation, the estimating effort is centered on taking off quantities, while this research will tried avoiding this limitation.

Spreadsheets vs. Commercial Estimating Software

In 2002 a study (Information Technology Survey for the Construction Industry) in USA by CFMA shows that Microsoft Excel was the most popular estimating software even in the largest-companies group with a 33 percent. Others use specialized estimating software 26 percent use Precision Collection of Timberline. Up to 5 percent of estimating software were the result of companies' own development "Developed in house", Table (1).

In Iraq a questionnaire by (Al-Hadythy, 2006) shown that Timberline not available in the market and it is unknown to the estimators with 100 % percentage. However, the estimators concerns about software products are that they want them to integrate with project management and scheduling. They also want the ability to change the assumptions, such as work crew breakdowns and productivity rates that govern calculations (Farah, 2005).

Limitations of Current Software

Software are applications by commercial vendors and their internal data format are proprietary, which is why they can not communicate their information directly with each other unless they develop specific translators for this purpose.

An architect may use a CAD package to produce a set of drawings. A quantity surveyor/estimator will then use these drawings to produce costing information and bill of quantities. A construction planner/scheduler will also use the drawings and bill of quantities to produce a set of construction schedule. Participants use their preferred software package, maintaining their own subset of the project's information. This approach, although

well established, does have a number of disadvantages (Marir et al, 1998):

- The existence of "information lag" between participants
- occurrence of errors when re-entering data
- The difficulty in gathering an overall view of the project for management purposes
- The difficulty in integrating software packages due to the lack of a common conceptual information model.

Architect's first responsibility is to meet the client's expectations in design quality as well as in budget. Widely used by architectural firms, CAD software like AutoCAD does not support any cost data storage on their platform. In order to generate the estimate, Architect/Engineer has to rely on other software. It could vary from a MS Excel spreadsheet to Timberline (Farah, 2005). Users need to calculate quantities by hands with their imagination due to the lack of data for quantity calculation (Lin, 2007).

The CAD graphic documents often exclude information needed for effective project planning. The information that is sufficient for project designs is often insufficient to meet the requirements of project planning (Chen and Feng, 2008). The major tasks of CAD are drawing and visualization (Lin, 2007). However, these are not considered as weaknesses of AutoCAD as this software is only a general drafting tool.

Therefore, the researcher has made an effort to help the practitioners in the construction management by developing the system that presented in this research (InCADEP), which will help the practitioners in the estimating and planning.

Integration in Construction

An increase in the scale and complexity of building production requires a larger number of participants and more efficient communication among them. Because of the fragmented nature of the construction process, construction organizations have always searched for new ways to integrate both inter and intraorganisational functions (Nam and Tatum, 1992) as mentioned by (Kanoglu and Arditi, 2004). Indeed, participants in the construction activity have always encouraged researchers to focus on integration issues with

the hope that such research could eliminate the consequences of the currently existing fragmentation in the construction industry. Attempts to deal with fragmentation can be carried out at three levels, namely at the (Kanoglu and Arditi, 2004):

- Organizational level: including approaches such as partnering and design/build contracting,
- Process level: including methods such as lean production, supply chain management, just-in-time delivery, and
- Virtual level: including software and hardware packages aimed at integrating the activities of the parties such as the integrated system described in this research.

Computer Integrated Construction

The concept of Computer Integrated Construction (CIC) is mainly derived from manufacturing industry such as Computer Integrated Manufacturing (CIM). CIC defines a goal to make "better use of electronic computers to integrate the management, planning, design, construction, and operation of constructed facilities". In this context, "integrate" means to "combine" the individual elements to optimize the performance of whole facility (Sanvido and Medeiros, 1990). CIC describes a future target stage of the use of IT in construction. The key factor in CIC is the integrating of the different computing applications used in the life cycle of a building. Such integration will take place via automated digital data transfer between applications (Bjork, 1994).

involved in the project. Off-the-shelf stand-alone packages can now be integrated to develop cost-effective CIC systems that are as powerful and effective (Elzarka, 2001).

It is well known that integration of computer applications in the areas of planning, design and construction would help in saving time and cost of construction and in improving productivity (Arun and Appa Rao, 2005). CIC systems automate many of the labor- intensive tasks associated with construction management of new facilities (e.g. building). The main objective of CIC systems is to communicate data to all project participants, throughout the project's entire life cycle and across business functions (such as design, estimating and scheduling). Information processing requirements for many of these construction business functions are currently handled by computer systems that are not integrated. This creates a situation, which many refer to as "islands of automation". Through integrating individual computer systems, CIC systems improve the effectiveness of the entire management process by enabling the communication of information among all business functions through the entire project development process (Elzarka, 2001).

Many large construction companies use integrated systems that cost thousands or even tens of thousands of dollars to purchase (more money than most small-to-medium size builders can afford) (Christofferson, 1999), or have developed CIC systems in house (Elzarka, 2001).

Previous research has shown that at the heart of any effective CIC system is a 3D CAD model (Elzarka, 2001) (Arun and Appa Rao, 2005). Such a CIC system combines 3D CAD models with other project planning and management tools to integrate all parties

CAD Integration with Estimating

This automated model makes direct use of the original electronic CAD files for measurement. The benefits range from cost and time savings to improved flexibility in calculating the cost impact of different what-if scenarios (alternatives) (Staub et al, 1998). In the

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Associate General Contractors (AGC) estimating text Construction Estimating and Bidding, several concerns are mentioned concerning integrating CAD with estimating (Miller, 2001) (Alder, 2006). These concerns are listed below (Miller, 2001):

- Who is responsible for quantification errors?
- What software will be universal enough for use?
- How does the architect and/or engineer preserve its copyright when it distributes its total design in a form that can be easily modified and copied by others?

Additionally, the AGC states that the technology may assist the estimator "but will always have many limitations" (Swenson et al., 1999) as mentioned by (Miller, 2001). The technology of CAD integration may in the future play a larger role in the takeoff process (Miller, 2001).

Several studies have been conducted at Stanford University to demonstrate the abilities of estimating using CAD. One study found that those who used CAD software for estimating recorded an 80% reduction in required time to complete an estimate with an accuracy margin of error of +/-3% (Schwegler et al, 2001) as mentioned by (Alder, 2006).

Proposed Approach

The results of design of building from CAD can be appropriately placed in the VB. The building may consist of several components. The CAD model can be used through the integrated system to extract the quantity of different components of the building. The quantity data extracted can be exported automatically to MS Excel spreadsheet. The database can also be modified interactively by the user to input the required data. The database contains This integrated system has been integrated with objects of the computer applications using

information for crew/team productivity rate, unit cost and other parametric. The list of construction activities, their dependencies and estimated duration of activities can be exported automatically to MS Project for generating the construction schedule.

The integration approach described above, it contributes towards automation in construction. It may be noted here that the "approach" is conceptual in nature and it is possible to use it with different levels of details and sophistication.

System Development and Implementation
System Description

The Integration of Computer Aid Design with Estimation and Planning (InCADEP) was developed to facilitate the construction management of buildings projects by integrating the following off-the-shelf applications:

- AutoCAD for drafting the model. AutoCAD contains drawing and editing functions necessary to produce model of building components.
- Microsoft Access database for storing historical project information on crews, productivity and unit costs etc.
- Microsoft Project scheduling system to scheduling the project.
- Microsoft Excel spreadsheet to report the bill of quantities in a convenient spreadsheet format for subsequent manipulation and printing.
  The integration of computer applications is carried out under Microsoft

Windows operating system. All components of the system are integrated by using Visual Basic and ActiveX automation technology, as illustrated in Figure (2)

VB and ActiveX automation technology. VB plays the role of "glue" that holds together

many objects (individual software) applications and packages. Here in this system, VB provided the capabilities to construct user interfaces and access to other software. The operation of the Flow chart as shown in figure (3).

System Requirements and Limitations

- AutoCAD scale should be (1:1).

- All building components must be drawn in one drawing, i.e. one AutoCAD drawing file (*.dwg) and different specific layers names.

- Each door and window should be drawn as a block (for example Door1 drawn as block named 24D1 1_1).

- Need four elevations for building, stairs neglected.

- The cost of the activities is estimated using activity quantities that extracted from the AutoCAD drawing and the cost information stored in database or entered by the user. Information cost should be as unit cost/unit of measure.

- The production rate for an activity is assumed to be fixed along the activity duration (production rate should be as quantity/day).

- The duration of the activities is estimated using activity quantities that extracted from the AutoCAD drawing and the productivity rate information stored in database or entered by the user.

- The precedence of the activities collected from practical constraints governing the construction only and without overlap between activities. Note here the user can enter precedence before exporting data to MS Project.

developed system is represented by the overall system

- The schedule generation is for ground floor only.

System Operation

If the user does not saved database, the user should be enter the unit cost of each item (for example 12,000 ID per square meter for plaster) and enter the production rate per day for each item (for example finishing 100 m2 per day for plaster). The one how use the system can enter the cost by Iraqi Dinar "ID" or US Dollar "$", and the production rate consider in this case depend on the experience of the user.

If the user click on the "Import from ►AutoCAD", Figure (4), the "Open" file dialog box will appears, and the format of file type is limited to (*.dwg) to open only AutoCAD drawing. "Import from ►AutoCAD", allow for automatic extraction of quantities (length, area, volume, each/No. can be calculated) of various components of the building from the CAD model (like area of plaster, number of specific doors, etc). The user can perform the takeoff for the entire building; InCADEP will loop through all the elements contained in the model and calculate its quantities. The quantities will output in the table as shown in Figure (6). The unit cost is then retrieved from the database and the total price is calculated. In this menu "Import from ►AutoCAD", the graphical information convert to textual (non-graphical) information and the user can deal with this textual

Information in easy way more than the graphical information.

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Data from this table can be exported automatically to MS Excel spreadsheets just by a click (File menu and then export to ► Excel), Figure (5), which can be kept as a separate file for bill of quantities. This can be used for further estimations. If user click on the "Export to ► Excel", the "Save As" file dialog box will appears, and the format of file type is limited to (*.xlcx \ *.xlc) to save as MS Excel spreadsheet. Then the user first enter "File name" and then click "save", the InCADEP automatically open the MS Excel and fill the cells with the required information like (description, quantity, ….etc).

InCADEP also contain a "Digitizer" or "On screen takeoff", which can measure (length and area) for image\scanned drawings, support (*.jpg, *.wmf and *.bmp) data format. First, the user should enter scale of drawing (by input the known distance between two points), and then can measure distance between two points and the horizontal and vertical distance for this points; or the user can measure the area and the perimeter.

The Implementation Of The System (Incadep)

The developed system was designed for reinforced concrete building projects. However, the system can be easily modified to cover all types of projects, since the main code of data exchange system is already exist. The system was designed to find: the total volume of foundations, columns, beams, and slabs concrete; Total number of doors and windows; area and volume of brick; total length of DPC; area of plaster and cement plaster and ceramic; area of roof; area of floors etc. The output of system in MS Excel is as shown in Figure(6) & (7).

Conclusions

The following points have been identified as the overall conclusions of the research:

1. Design, cost, and time integration is possible with today's off-the-shelf software products. The resulting benefits include faster estimating time, fewer takeoff errors, better documentation and reproducibility of the estimating process, and the ability to release a construction schedule electronically with the whole project prior to construction.

2. It is possible to prepare information of the BOQ and construction schedule for the building automatically (with least user interaction) by taking the results from the AutoCAD. A special feature of the system is the CAD modeling facilitating capability to extract quantity. A consequence of this is that project management software will be much easier to incorporate and also can have direct access to the design data from such integrated system.

3. The utilization of integrated systems will become more and more important as the popularity of the design/build project delivery system continues to increase. In the design/build approach, more business functions are performed by the same company and as a result, their integration to share data becomes more vital.

4. The integration of AutoCAD and computer based construction project management software can be utilized to reduce fragmentation and to bridge

existing gaps between disciplines within the AEC industry.

5. With the continuous development in BIM and improvement of programming capability (such as ActiveX automation technology), the potential application of an integrated system in construction practice can no longer be ignored. The industry is also eager to capitalize on this potential. This research provided a vision for meeting the vital, critical and urgent needs by the construction industry for integration tools that enhance the sharing of project information.

6. Integrating design, cost, and schedule information can help a project team to improve the efficiency of the planning and estimating processes. Design-cost integration supports the automatic calculation of quantities, thus shortening estimating time and eliminating the duplication of effort that exists in current estimating practices. In addition, it allows a project team to quickly evaluate the cost impact of different design and specification alternatives, and provides electronic validation that all the items in the CAD model have been included in the estimate. Decisions are expected to be made faster and to become more reliable.

Recommendations

1. The ability to develop integrated systems should entice the construction industry to use these systems. AutoCAD available today, with its ability to link to other software has made such development possible.

2. The IFC standards once fully developed will enhance such integration. However, it is vital to address integration within a business context which is mainly related to process, human and cultural issues.

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Table (1) Estimating software used by U.S. general contractors (CFMA, 2002)

Software (vendor)	Used
Excel (Microsoft)	33%
Precision Collection (Timberline, now sage)	26%
ICE-2000 (MC2)	11%
Heavy Bid (HCSS)	6%
Other	19%
Developed in house	5%

```
┌──────────────────┐            ┌──────────────────┐
│   AutoCAD        │            │   MS Access      │
│   Drawing        │            │   Unit cost,     │
│ Extract Quantity │            │ productivity, etc│
└──────────────────┘            └──────────────────┘
           \                        /
            \                      /
          ┌──────────────────────────┐
          │  Visual Basic ActiveX     │
          │    User Interface         │
          │      InCADEP              │
          └──────────────────────────┘
            /                      \
           /                        \
┌──────────────────┐            ┌──────────────────┐
│   MS Excel       │            │   MS Project     │
│ Quantity takeoff &│           │   Generation     │
│ Bill of Quantities│           │   Scheduling     │
└──────────────────┘            └──────────────────┘
```
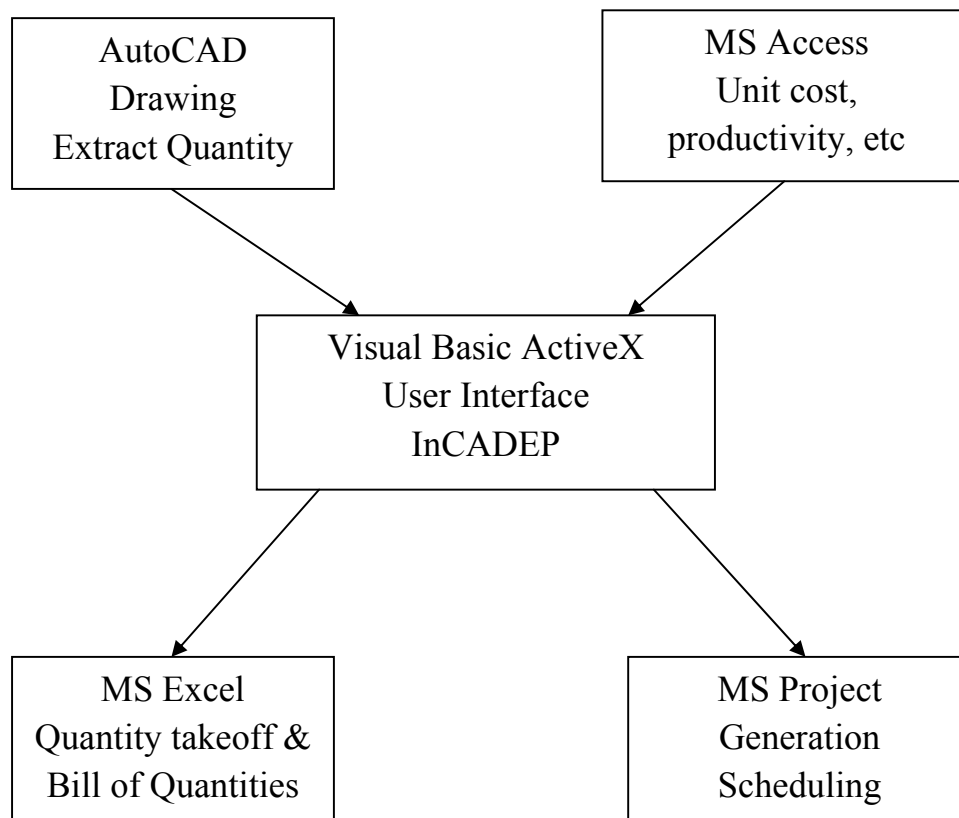
Figure (1) Architecture of Integration

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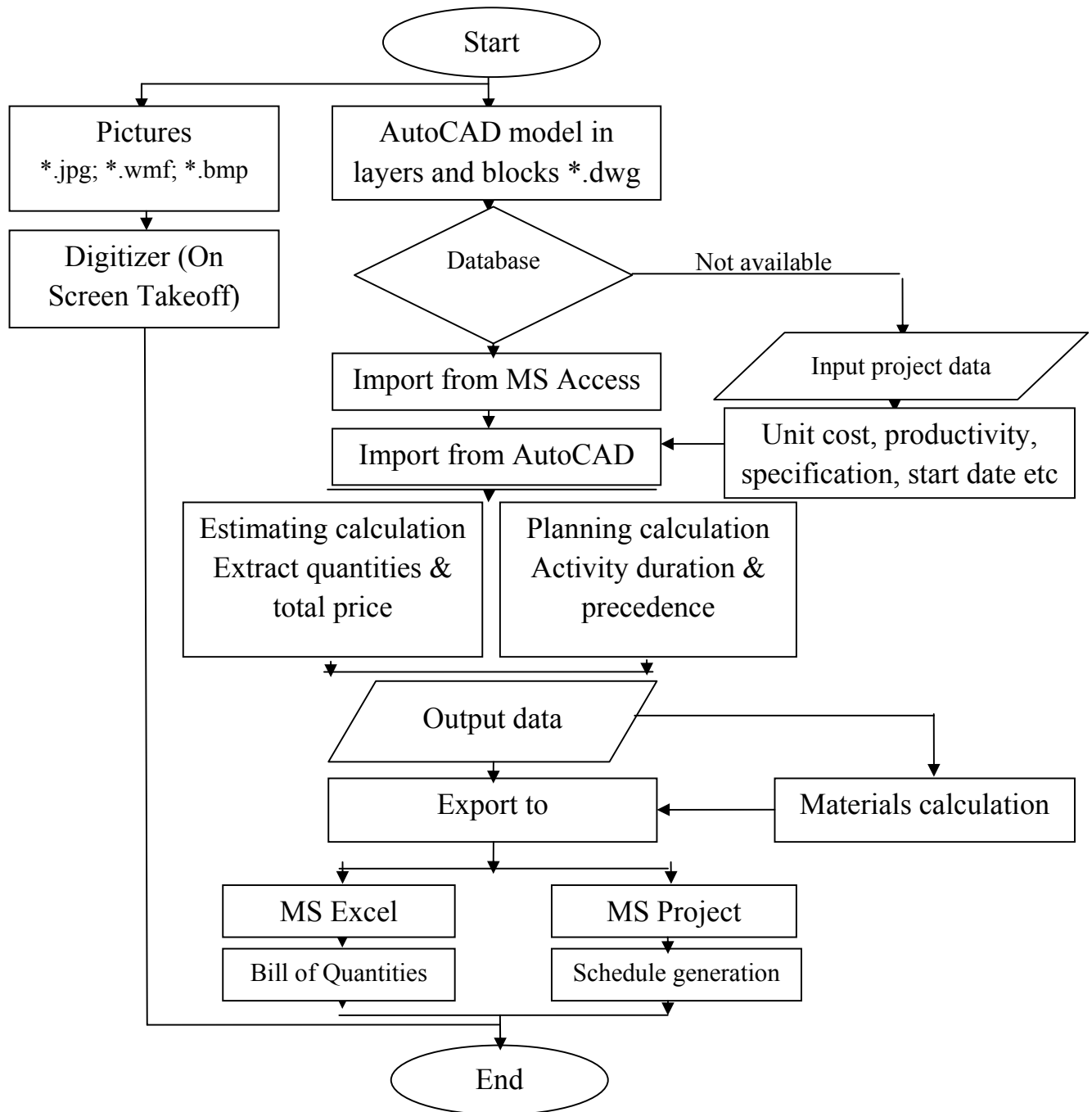
Figure (2) Overall system flow chart
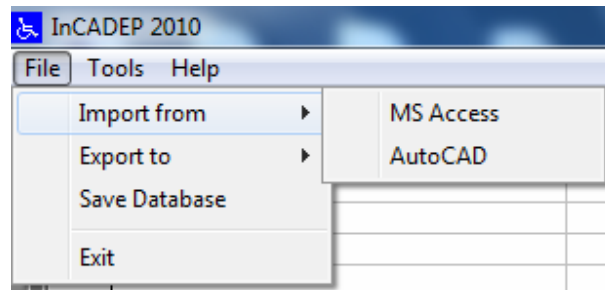
Figure (3) Import from menu
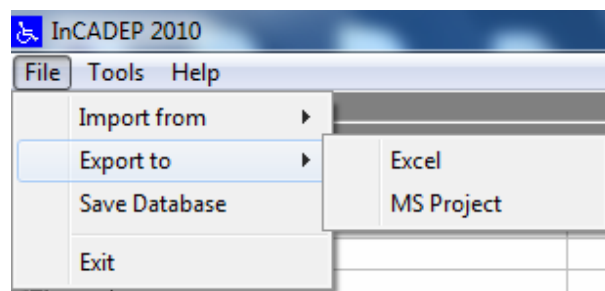
Figure (4) Export to menu

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Figure (5) Output of InCADEP

1	Description	Unit	Quantity	Unit Cost	Price
2	Excavations	m3	352.65	10000	3526500
3	Area under Foundations(Hard Core,Blind	m2	227.52	5000	1137600
4	Foundation Concrete	m3	69.6	350000	24360000
5	Columns Concrete	m3	15.44	400000	6176000
6	Beams Concrete	m3	22.65	400000	9060000
7	Slab Concrete	m3	91.19	375000	34196250
8	Brick under DPC	m3	48.12	416666	20049968
9	DPC 24	m.l	175.93	10000	1759300
10	Brick above DPC	m2	660.54	50000	33027000
11	Roofing	m2	582.76	30000	17482800
12	Plaster of Walls & Ceilings	m2	736.36	12000	8836320
13	Cement Plaster of Walls & Ceilings & Ext	m2	723.71	14000	10131940
14	External Finishing	m2	628.12	30000	18843600
15	Ceramic of Walls	m2	328.41	30000	9852300
16	False Ceilings	m2	170.66	20000	3413200
17	Floor Tile1 30 x 30	m2	463.33	1000	463330
18	Floor Ceramic	m2	4.24	30000	127200
19	Doors and Windows Works				0
20	Door1 : 2.4 x 1.5	each	1	325000	325000
21	Door2 : 2.1 x 1	each	4	200000	800000
22	Door3 : 2.1 x 1.5	each	1	275000	275000
23	Door4 : 2.4 x 1.5	each	2	320000	640000
24	Door5 : 2.1 x 1	each	2	190000	380000
25	Door6 : 2.1 x 0.8	each	1	150000	150000
26	Window1 : 1.1 x 1.2	each	2	160000	320000
27	Window2 : 0.5 x 0.6	each	1	50000	50000
28	Window3 : 1.6 x 1.5	each	1	290000	290000

Figure (6) MS Excel window

Quality Evaluation of Al-Rasheed Ready Concrete Mixture Plant By Using Six Sigma Approach

Ali Amer M. Hasan Karakhan & Dr. Angham E. Ali Alsaffar

Abstract

The objective of this research work is to evaluate the quality of central concrete plant of Al-Rasheed Company by using Six Sigma approach which is a measure of quality that strives for near elimination of defects using the statistical methods to improve outputs that are critical to customers. The fundamental objective of Six Sigma methodology is the implementation of a measurement-based strategy that focuses on process improvement and variation reduction to reach delighting customers, and then suggesting an improvement system to improve the production of concrete in Al-Rasheed State Contracting Construction Company.

A field survey includes two parts (open and close questionnaire) that aimed to get the data and information required for achieving the research where the answers of questionnaire sample have led, during the application of DMAIC improvement cycle, to identifying the potential possible reasons that caused quality deviations in concrete works. Two programs have been used: First, 'Sigma Level Calculator' which is formulated by the researcher to measure the components of the processes performance. Second, 'QI Macros Lean Six Sigma SPC Software 2011' which uses the statistical tools of Six Sigma DMAIC methodology for: identifying the root causes of defects, analyzing the data, determining capability and stability of process. It is concluded that the processes sigma level for the concrete works quality is 2.41 σ and 181,070 DPMO which is considered too bad as compared with the current global competition.

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(   )

Sigma Level Calculation   :   .

QI Macros Lean Six Sigma SPC Software 2011   .

:

181070   2.41   .

.   "

1. Introduction

Over the last twenty years, Six Sigma has received wide acclaim as a methodology, process and vision to accomplish process improvement. It has been successfully implemented in many industries, from large manufacturing to small businesses, from financial services, insurance industry to healthcare systems beside, its effective role in the construction and banks sector. Six Sigma means a business management process that provides tangible business results to the bottom line by continuous process improvement and variation reduction. As a data-driven, statistically-based approach, Six Sigma aims to deliver near-zero defects (as defined by the customers) for every product, process, and transaction within an organization. In other words, it is a practical approach to running a business with the involvement of each resource at all levels. It is a stronger emphasis on capturing 'the true voice of the customer' by clearly 'understanding the needs and demands of customers' for today and tomorrow (Hasan, 2011).

2. Research Objectives

The objectives of this research are represented in the following points:

1. Implementing Six Sigma DMAIC improvement cycle to evaluate and analyze quality of central concrete plant at Al-Nahrain University (the Case Study).

2. Preparing a program named 'Sigma Level Calculator' to calculate the sigma level, DPMO, and percentage of yield which help measuring the actual performance during the Measure Phase of DMAIC cycle.

3. Proposing a suggested improvement system to improve and control the production of concrete in Al-Rasheed Company.

4. Proposing an organizational structure of Quality Improvement Department for Al-Rasheed Company.

3. Six Sigma

In 1980s, Motorola's top leaders conceded that the quality of its products was awful. As a Result, the managers started to think of a new approach to improve quality (Chen et al., 2006).

In 1987, Robert Galvin, at that time CEO at Motorola, together with Bill Smith, Mikel Harry and Richard Schroeder created a new improvement program that was named Six Sigma. The program was inspired by Japanese work and strongly influenced by Juran's thoughts (Klefsjö et al., 2007).

Due to Six Sigma, Motorola managed to reduce their costs and variation in many process and won the Malcolm Baldrige National Quality Award in 1988 (Kessler & Padula, 2005).

Chowdhury (2001) defined Six Sigma as "a statistical measure and a management philosophy that teaches employees how to improve the way they do business, scientifically and fundamentally, and how to maintain their new performance level. It gives discipline, structure, and a foundation for solid decision-making based on simple statistics" (Pheng & Hui, 2004).

The principles of Six Sigma can be distilled into the following themes (Tehrani, 2010):

1. Genuine focus on the customer. While profits and statistical tools get the most publicity, the emphasis on customers is the most remarkable element of Six Sigma.

2. Data and fact-driven management or metrics (i.e., numbers) for decision making. It takes the concept of 'management by facts' instead of basing on assumptions in building up key measures to calculate the success of an organization.

3. Process focus, management, and improvement. Six Sigma positions process as the key vehicle of success, measure the success and improve the efficiency, effectiveness and customer satisfaction, etc.

4. Proactive management. It means focus on eliminating the root causes of defects before their occurrence instead of trying to manage them after it has occurred.

5. Boundless collaboration. It means working to break down barriers and improve teamwork.

6. Drive for perfection, tolerate failure. Although these ideas sound contradictory, they are actually complementary. i.e., despite striving for perfection, failure is allowable, to manage them properly.

4. Six Sigma Dmaic Methodology

Six Sigma is divided into two methodologies, DMAIC and DFSS/DMADV. DMAIC (which is an acronym for Define, Measure, Analyze, Improve, and Control) focuses on improving existing processes and performance (Ferrin et al., 2002).

4.1 Define Phase

In this step, defining problems that can be fixed is an important key. It is important to pick problems that are costing the company most or are giving you the most problems (Chowdhury, 2001).

Besides, define the customers, their requirements, the team charter, and the key processes that affect the customers. Goals and/or objectives of a certain process are then set based on the customer's requirements (Pheng & Hui, 2004).

SIPOC perspective (which stands for Suppliers–Inputs–Processes–Outputs–Customers) can be used in the define phase to solicit the Voice of the Customer (VOC) and determine not only the wrongs of a particular product, or service but also to identify the important inputs which lead to the outputs through a series of processes (Klefsjö et al., 2007). SIPOC diagram is a conceptual model used to help define the boundaries and critical elements of a process without getting into so much detail (Pande & Holpp, 2002).

4.2 Measure Phase

In this step, the Black Belt calculates how many errors are made. In other words, measures the current performance of the process (yield, DPMO, sigma level, etc) (Chowdhury, 2001).

Six Sigma offers the following formulas to calculate percentage of yield and number of defects per million opportunities (DPMO) (Tehrani, 2010). **Table 1** shows the relationship between sigma level and these metrics values

while eq. (1) and eq. (2) are the formulas of calculating the yield and DPMO.

$$Yield= (correct~items~/~opportunities) \qquad (1)$$
$$DPMO= (defects~/~opportunities~) \times 10^6 \qquad (2)$$

Table (1): Relationship among sigma level, defect rate and yield (Park, 2003)

Sigma Level	DPMO	Yield (%)
2σ	308 770	69.1230
3σ	66 811	93.3189
4σ	6 210	99.3790
5σ	233	99.9767
6σ	3.4	99.99966

4.3 Analyze Phase

In this step, understand and analyze the data collected by using simple statistical tools as well as the process to determine the root causes of the problem that need improvement (Pheng & Hui, 2004).

In construction, the main task is to identify when, where and why the defects occur in the project, which includes actual and potential problems by using Six Sigma tools (Tehrani, 2010).

4.4 Improve Phase

In this step, Six Sigma project aims to eliminate the identified defects through the knowledge derived from analyze phase. Motivating the team and effective coordination of the different processes and activities and their interface are required to improve the entire construction project (Tehrani, 2010).

4.5 Control Phase

In this step, after finding root causes, alternatives for improvement are considered and improvements made. Then, further data is collected to ensure that improvements have occurred and control plan is put in place to ensure the changes are permanent. In a nutshell, this step ensures that the process improvement is not lost over time (Schroeder, 2008).

The ideal members of Six Sigma team, from top manager to entire involved people are shown in details in (Pheng & Hui, 2004) and (Tehrani, 2010) sources.

5. Field Survey

For the purpose of achieving the goal of this research, it is necessary to work in the open and close questionnaire method as follows:

5.1 Open Questionnaire

This step is considered the following processes which are: literature survey, field visits and personal interviews to help designing the questionnaire form.

The literature survey of the research helped much in the preparation of the questionnaire form. In addition, information was obtained from surveying various literatures and researchers in the field of controlling the concrete quality.

Some sites, for manufacturing concrete, have been visited in order to know the basic stages of producing concrete on the site.

Interviews were also made with a selected number of well-experienced personnel in the field of construction to know the most common current problems related to quality failure during the processes of producing concrete.

5.2 Close Questionnaire

The formulations of the questionnaire form were directed to accomplish the objectives of the research and it was formed of four axes:

1. First Axis: named 'General Information' which covers the personal information such as: name of the firm they work for, academic degree, specialization, current position and years of experience.

2. Second Axis: named 'Quality and Six Sigma' contains an introduction illustrating the concept of Six Sigma (generally and statistically), besides questions covers the quality improvement systems, statistical tools and mathematical methods.

3. Third Axis: named 'Concrete Mixtures' that covers all factors affecting the quality of concrete mixture.

4. Fourth Axis: shows the most common causes of deviations in the quality of concrete mixtures as shown later in Pareto.

6. Application of Dmaic Improvement Cycle

The Six Sigma process improvement strategy 'DMAIC cycle' (which stands for Define, Measure, Analyze, Improve and Control) aims at bringing process improvement by eliminating defects. This research includes the application of DMAIC improvement cycle Six Sigma at Al-Rasheed Company Project at Al-Nahrain University Campus (the case study).

The sequential five steps of DMAIC are primarily based on the application of statistical process control, quality tools, and both process capability and stability analyses.

6.1 Define Phase

In this phase, defining the problems should be specific and complete as possible. Problems are often initially identified very qualitatively, without much detail.

This research focuses on the problem of 'poor quality of concrete mixtures and the consequent deviation in the quality of building' whereas the business owner expects a high strength of cubes that can easily pass the compressive strength test because any defect could lead to: customer's dissatisfaction; extra labor and equipment to accelerate constructing; extra days and payment the penalty for delay.

6.2 Measure Phase

In this phase, after gathering data, the Six Sigma team has to decide what to measure and how do they measure it.

The defect is defined, according to the technical specifications of C30 mixture for foundations in the project of the case study, as 'all concrete cubes have not passed the compressive strength test based on the American Specification (ACI 318)'. Accordingly, it is noticed that 'from 243 products, only 199 have passed, which means there are 44 defects'.

After having both the number of correct items and defects, Sigma Level Calculator would

be used to calculate the current performance level as shown in **Fig. 1** while **Table 2** illustrates all the

outputs and calculations of sigma process level performance.
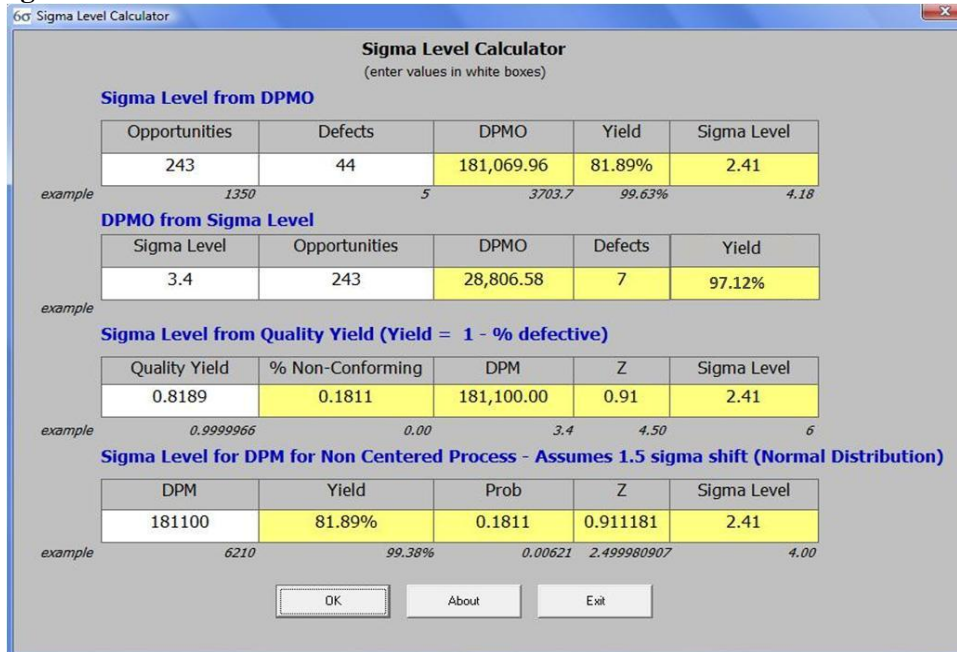

Figure (1) 'Sigma Level Calculator' Program

Table (2): Sigma Level Calculations

Evaluate and Improve Quality of Concrete (central mix plant process yield)			
Current (outputs)		Target	
Yield	Sigma level	Yield	Sigma level
81.89 %	2.41	97.12 %	3.4
DPMO		DPMO	
181,069.96		28,806.58	

6.3 Analyze Phase

In this phase, not only studying and analyzing the data statistically, but also identifying key process variables that cause failures and understanding root cause's behavior of why failures occurs as follows:

6.3.1 SIPOC Diagram

SIPOC diagram is kind of a high level process flow from Suppliers and their Inputs through the Process to the Outputs and Customers both internal and external. It is a graphic representation of how work flows through the company and show the sequence of processes.

SIPOC diagram forms the basis for understanding what actually happens in a process; so, issues can be identified and process can be improved. This is possible only if the preparation of SIPOC is managed correctly where it is noticed that the most common problems faced SIPOC's user is either putting in too much or too little details. **Table 3** shows the P part of SIPOC dia. which illustrates the sequence of processes during the stages of producing concrete on the site.

Table (3): P part of SIPOC Diagram

S I	P	O C
Process		
Start:		
Mix design then issued the check request		
High-Level Process Description:		
First, batching the materials; Next, mixing; Then, handling & transporting; Also, taking samples for testing; After that, casting; Following, compacting; Finally, finishing.		
End:		
Curing and removing forms		

6.3.2 Scatter Diagram

Scatter diagram is one of the most useful tools used to determine the correlation (relationship) between two variables. Correlations may be positive (rising), negative (falling), or null (uncorrelated) (Stevenson, 2005).

The values of compressive strength for concrete samples verses the date of casting are plotted on the vertical and horizontal axes respectively to show the kind of relationship between variables in a scatter diagram which is drawn by using the QI Macros as shown in **Fig. 2**.

According to the scatter diagram, the pattern of dots slopes from upper left to lower right and seem scattering rather than centering. Therefore, the relationship is a 'weak negative correlation'. The diagram also shows that the strength values are deceasing with the passage of time where it is

noticed that in the beginning, most results are high while in the end of the year they go down; i.e. the quality control of concrete production has been decreased with the passage of time.

6.3.3 Histogram

Histogram is a graphical representation, showing a visual impression of the distribution of data. It consists of tabular frequencies that represent a frequency distribution and rectangles whose areas are proportional to the corresponding frequencies (Schroeder, 2008)

Histograms are used in Six Sigma to establish variability or deviation from the center line of the target value in a bell shape; also, they are a way of doing a 'capability' studies. **Fig. 3** shows 'histogram with Cp and Cpk' which drawn by using the QI Macros.

There is a couple of index called Cp and Cpk which help to determine whether a process is capable or not. A Cp $\geq$ 1 means the process fits between the upper and lower specification limits; whereas Cpk $\geq$ 1 means the process is centered between these limits. Also, there are many other calculations shown in histogram (Hasan, 2011).

According to the values presented, the process is not capable (based on Cp and Cpk) and the histogram is moderately skewed to the left while many point are located outside the lower specification limit (LSL).

6.3.4 Control Chart

Control charts are the appropriate tool to monitor processes. They are useful to find unusual sources for variation. Samples falling outside the control limits are a signal for unusual sources and an investigation should be made to find the causes behind. The appropriate response to the signal is to stop the process at once and preventing defects (Nyrén, 2007).
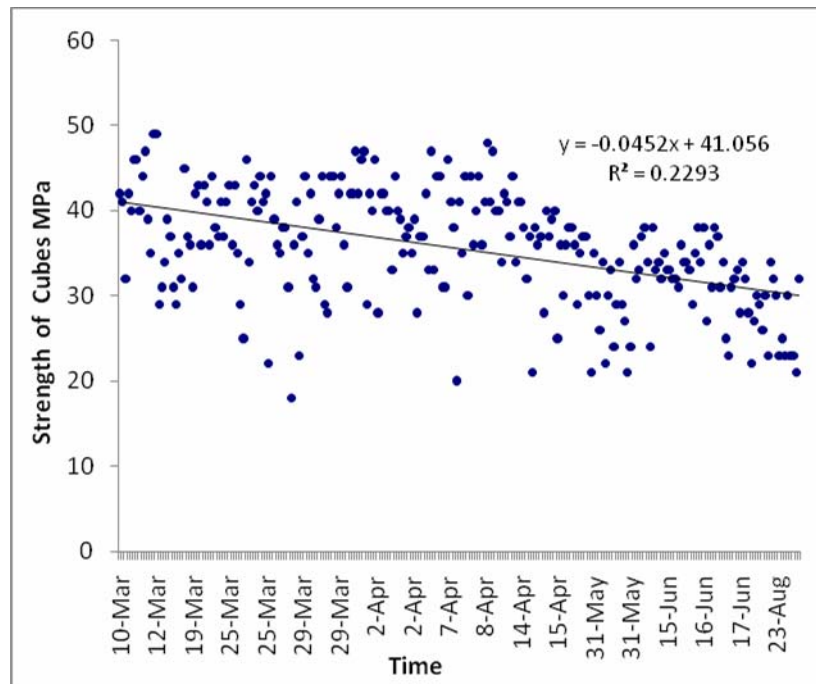
Figure (2) Scatter Diagram
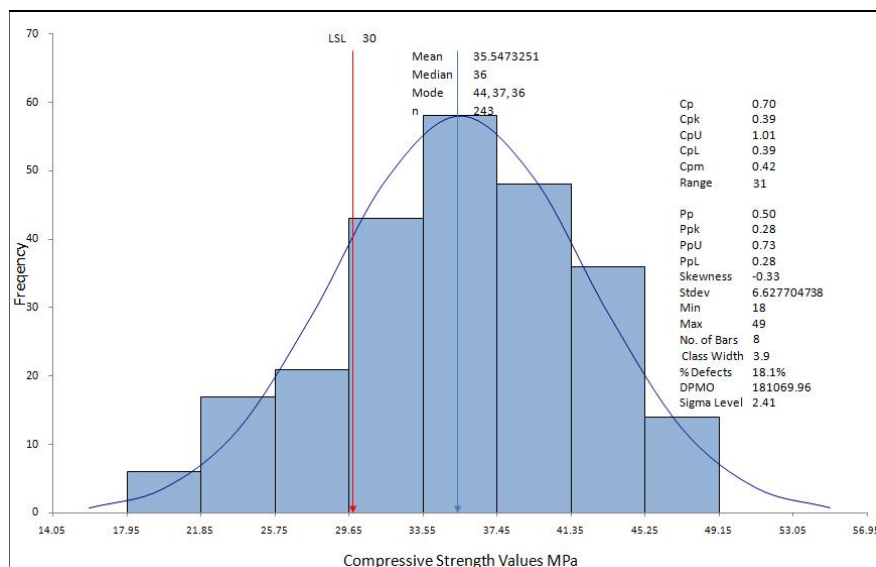
Figure (3) Histogram

There are so many different control charts that estimate μ and σ using the average and range of samples. The formulas to do this vary depending on the type of data (variable data such as time, cost, length, weight, etc. or attribute data such as number of percent defective) and the sample size. Each control chart's formulas are designed for these varying conditions. In variable charts, the XmR uses a sample size of 1, XbarR (2-10) and XbarS (11-25). In attributed charts, the c and np charts use small samples and fixed

populations; the u and p charts use varying populations (Arthur, 2004).

Accordingly, the right control chart for the data of this study is the XbarR charts which can effectively help evaluating the stability of processes. In other words, it helps evaluating if the trend of process is predictable or not.

Fig. 4 and **Fig. 5** show X bar - control chart and R - control chart respectively of the values of compressive strength testing. The 'QI Macros' has

been used in drawing these charts. From these two figures, the values seem scattered and out of

statistical control. Therefore the process is 'not stable' (unpredictable).
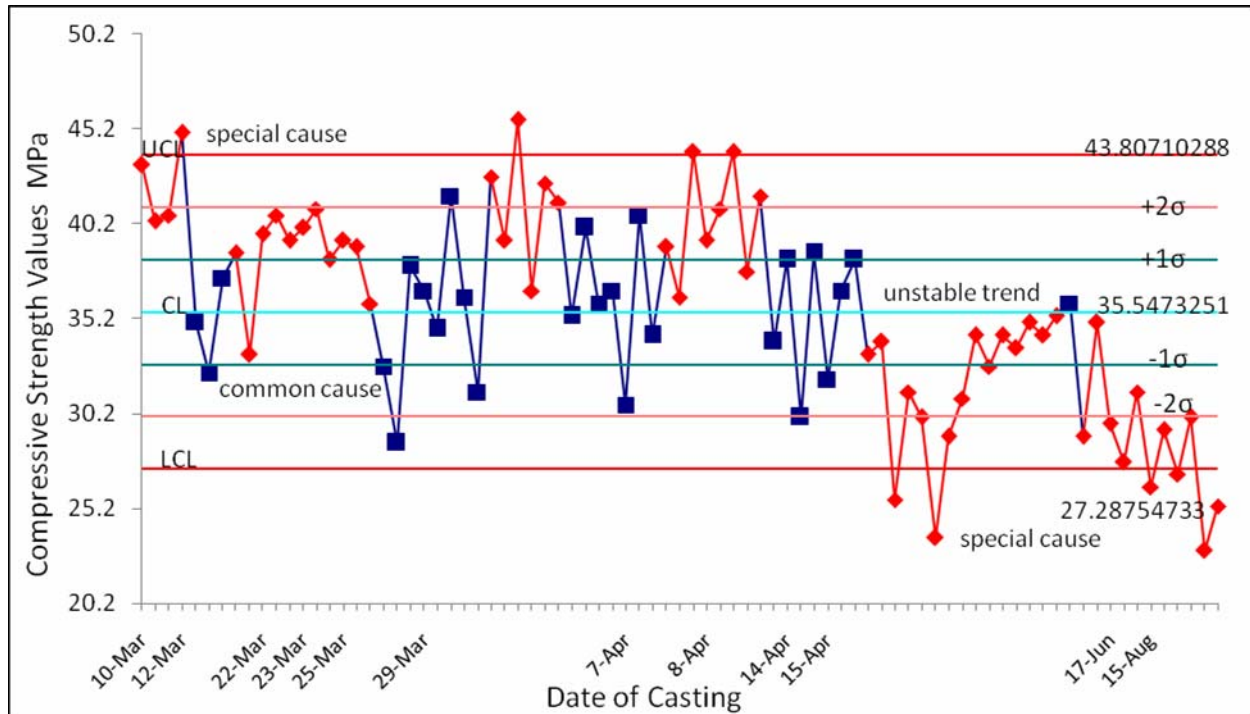
Figure (4) X bar - Control Chart for the Compressive Strength Testing
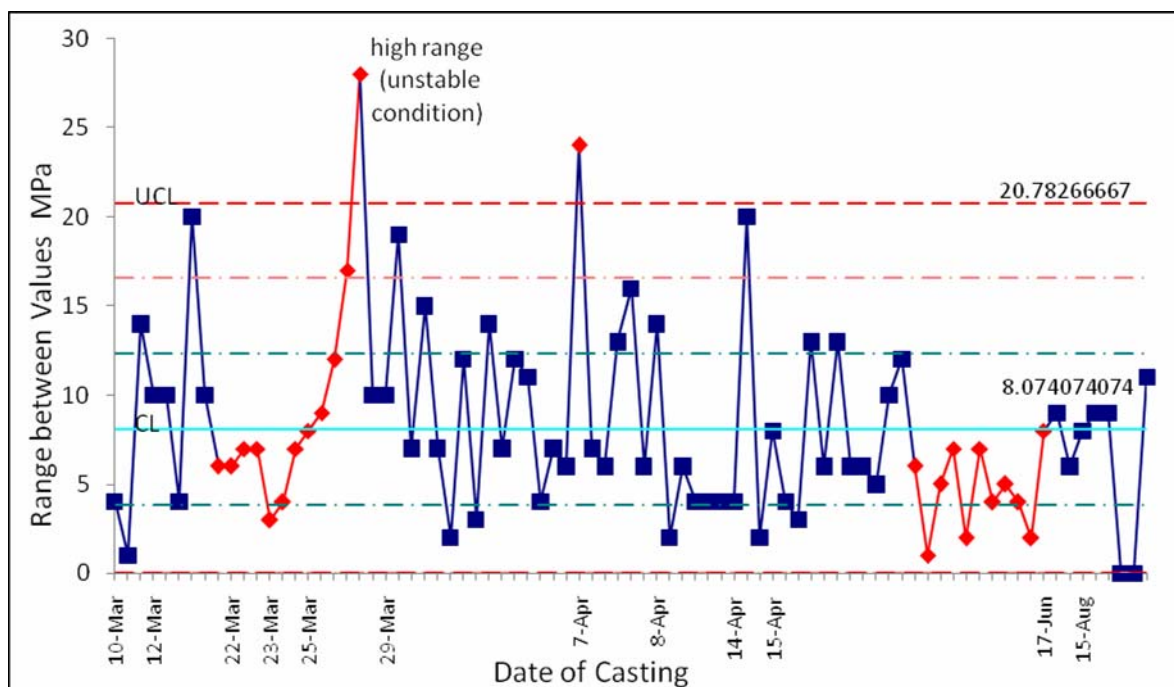
Figure (5) R - Control Chart for the Compressive Strength Testing

Additionally, it can be noticed that the values start to drop down with the passage of time especially since 31st May. Therefore, the control

chart, as shown in **Fig. 6**, is divided into two parts: 'before Summer' and 'in Summer' where it is noticed that before Summer the process is

almost stable while in Summer the values slope down and become unstable. Thereby, it is concluded that the main reason for this deviation may return to the 'high temperatures' in that period of year.

Histograms are a way of determining capability (does the process meet customer specification?), while control charts are a way of measuring stability (is the output of process predictable and consistent?). Specification limits

are set by customers and used in histograms whereas the upper and lower control chart limits (UCL and LCL) are calculated based on the data. The process of this study is neither capable nor stable which means improvement must be accomplished.
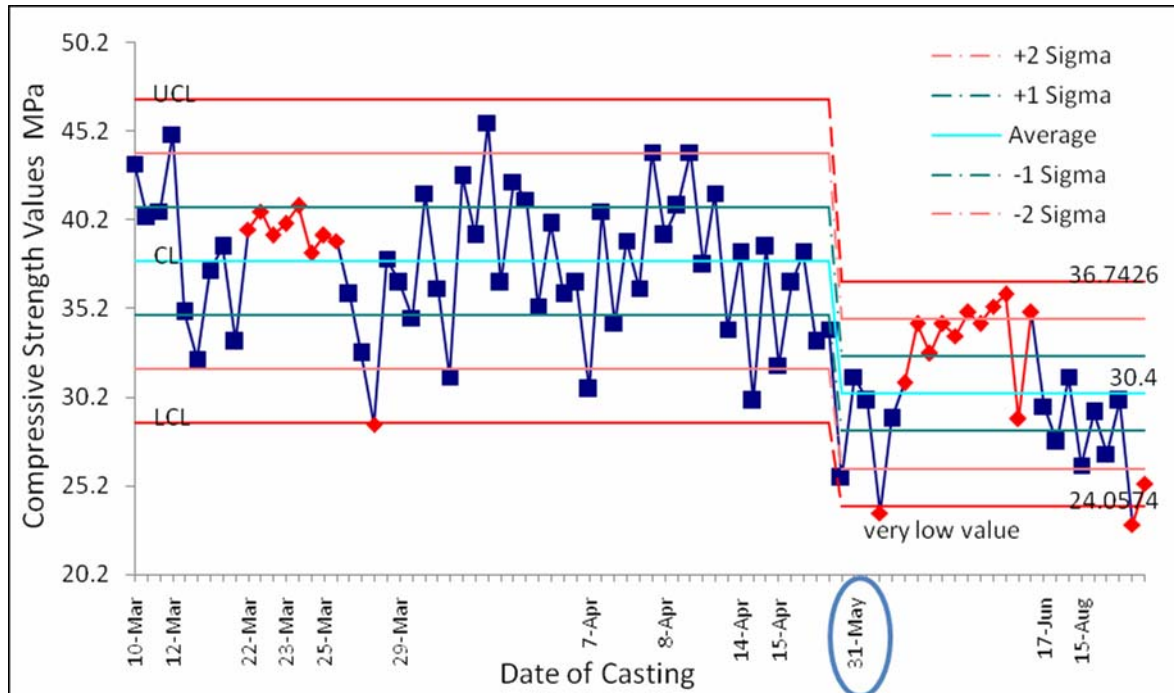
Figure (6) Process Change of the X bar - Control Chart for Compressive Strength Testing

6.3.5 Pareto Diagram

Pareto analysis is a technique for focusing attention on the most important problem areas. The Pareto concept, named after the nineteenth-century by Italian economist Vilfredo Pareto, is that a relatively few factors generally account for a large percentage of the total cases (e.g., complaints, defects, and problems). The idea is to classify the cases according to degree of importance, and focus on resolving the most important, leaving the less important (Stevenson, 2005).

The bars are placed from left to right in descending order to illustrate the most common causes of deviation in the quality of concrete mixtures according to the responses of respondents for the close questionnaire as shown in **Fig. 7** which is drawn by using QI Macros software.

6.4 Improve and Control Phases

The main task in these two phases is the elimination of the root causes of problems and developed process requirements that minimize the likelihood of the failures based on the knowledge and information obtained in previous phase or from the questionnaire lists and interviews. The team members should generate ideas for improving processes; then, evaluate these ideas to select the best potential solutions to implement them. These phases have been replaced by proposing an improvement system as shown later in this research.

7. Proposed Organizational Structure

An organizational structure of Quality Improvement Department has suggested to be adopted in Al-Rasheed Company instead of the small Quality Division that established since 2008. The Proposed Quality Improvement Department has a pivotal role as a second major

party after the top-management in implementing the suggested improvement system. The organizational structure of Quality Improvement Department has included five divisions, as illustrated in **Fig. 8**, which are:

1. Six Sigma Division: which aims to promote Six Sigma principles and practices the five phases of DMAIC and offer opportunities for employees to increase
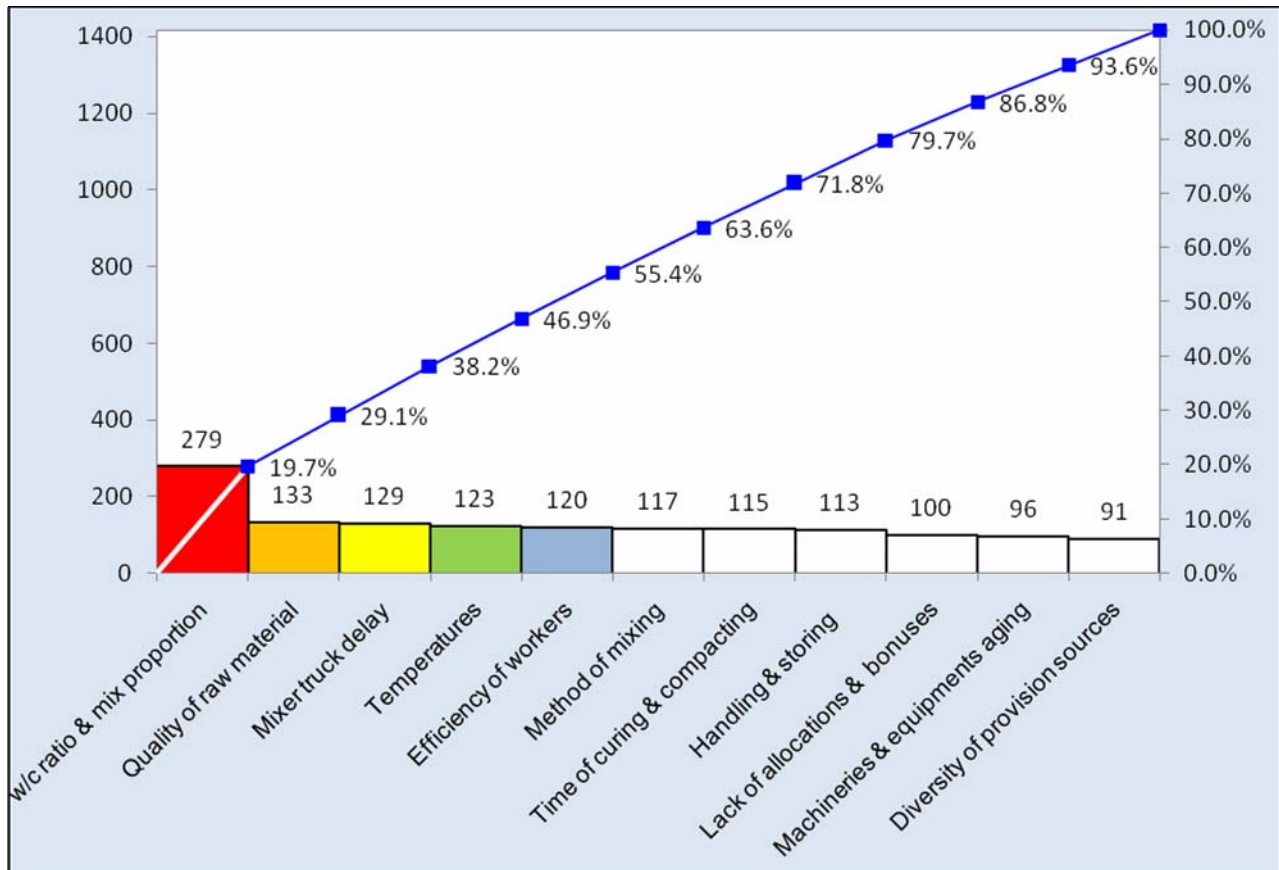
Figure (7) Pareto Diagram for Analyzing the Problems

Their knowledge of Six Sigma. As well as, supports training programs by providing plans and ensures that everybody on the company knows the reason of adopting Six Sigma.

2. Training Division: where the term training refers to the acquisition of knowledge, skills, and competencies as a result of teaching. The members of this division must prepare training schemes which can be divided into three categories. First is 'Six Sigma course' to all personnel which gives an orientation to the Six Sigma philosophy. Second is 'statistical course' to

specific engineers who concerned in the application of the statistical tools. Third is 'manpower course' to all workers to develop their skills through the process of the concrete.

3. Documentation Division: this division deals with documenting everything (such as the progress of work, result of testing, quality reports, etc.) manually and electronically.

4. Design Division: this must be included numbers of well-experienced engineers to doing missions like: revising and verifying the design; cooperation to design specification limits; detecting deviation; and providing advice and guidance.

5. Examination and Inspection Division: this consists of engineers and technicians to perform: supervision of testing for each of raw materials, equipments and devices; and works skills as well as taking specimens and issuing reports.
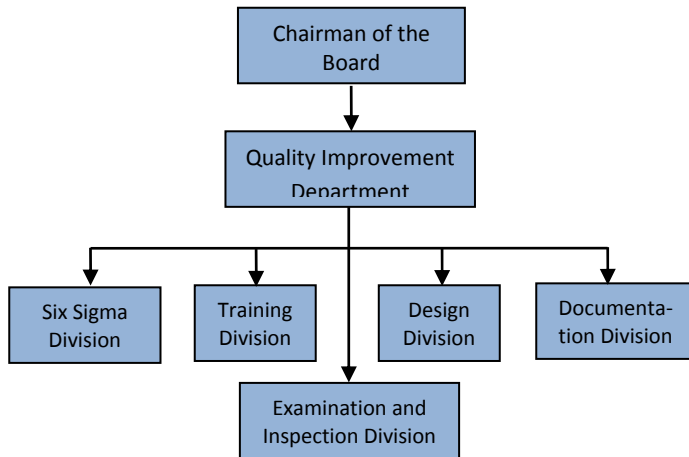
Figure (8) Proposed Organizational Structure of Quality Improvement Department to Al-Rasheed Company

8. Suggested Improvement System

In accordance to the results of the analyze phase, a formulated model has created to be adopted in Al-Rasheed Company in order to improve and control the quality of concrete production. The basic elements of the 'suggested improvement system' are summarized in the following items:

1. Input Control.
2. Processes Control.
3. Output Control by FISH Cycle.

8.1 Input Control

Input such as raw materials, devices, equipments, machineries and specialized technical staff are used by the process to produce the output.

8.1.1 Raw Materials Control

The most prominent procedures that must be included in this stage are:

1. According to 'Contract Condition for Civil Engineering Works' (clause 37). It is

suggested to send a team of experienced engineers to the headquarters of manufacturing, prior to complete the purchase of raw materials, to perform tests and evaluate the quality of materials before buying and shipping them to the site in order to overcome wasting of time and effort on the processes of transporting and storing invalid materials.

2. Registration of the entrance of the material from suppliers in software used for this purpose and saved in computer as a permanent document which can help evaluating the efficiency of suppliers.

3. Determining the required material; then, buying the right amount after deep studies; next, providing an appropriate storage for materials; after that, testing the materials; finally, documentation of all information.

Purchasing the materials of high quality can help companies avoiding causes of deviation in the quality of concrete mixture as shown in the second bar of Pareto chart, **Fig. 7**.

8.1.2 Devices and Equipments Control

Organizations need to purchase or hire items in order to conduct their business. The proposed system aims to guarantee the continuity of work equipment to achieve the purpose of their existence which is introduced the best performance at the lowest cost and highest degrees of safety through adopting the procedures of preventive and predictive maintenance instead of the remedial maintenance.

The main goals of this stage are:

1. Selecting the right acquisition policy; where equipment may be purchased, hired or hired with an option to purchase later.

2. Providing a convenient place for equipments.

3. Reducing periods of breakdown to a minimum and improving the productivity of equipments to a maximum.

4. Complying with safety regulations to ensure staff safety.

5. Reducing the number of spare parts, unless they are necessary, to avoid freezing of capital.

The following parties are suggested to be responsible for adjusting the work of equipments:

1. Maintenance Unit and its workshops.
2. Stores Division.
3. Purchasing Department.
4. Financial Affairs Department.
5. Quality Improvement Department.

8.1.3 Personnel Control

The human resource is the master key to accomplish the quality requirements; therefore, it has become necessary to establish the concept that 'quality is everyone's responsibility'.

The field survey have reflected that most of the workers in construction projects are temporary labor and have not had enough efficiency that can qualify them to work on sites. Therefore, two important functions are suggested to solve the problem referred to above. These procedures are:

1. Establishing a new system for hiring personnel permanently instead of depending on the temporary labors.

2. Now, after having a permanent staff, the company must be sure that new employees receive the proper indoctrination by offering *training courses* to develop their skills and increase knowledge of Six Sigma to accomplish mutually beneficial relationship between organization and employees.

These responsibilities should be managed by:

1. Training Division.
2. Six Sigma Divisions.
3. Human Resources Department.
4. Quality Improvement Department.

8.2 Processes Control

Organizations must remember that processes control and producing high-quality products may ensure customer satisfaction. This stage should control:

8.2.1 Examination and Inspection

Testing and inspection are usually used to determine whether the item or activity is in line

With the targets or not. The next stations of examination and inspection must be achieved during the process of concrete production:

1. Suggested station for testing and inspection of the raw materials at the provision sources by sending committees from the Purchasing and Quality Improvement Department to assure quality of materials 'before' buying and shipping them to the site.

2. Station of testing and inspecting the received raw materials, from provision sources, on the site.

3. Suggested station for inspecting during the process of concrete production inside the concrete plant by a permanent reprehensive from each of Quality Improvement Department and Resident Eng. Office in order to verify and monitor the progress of concrete production in accordance to plans.

4. Suggested station for testing the fresh concrete in the field as recommended by the American Concrete Institute (ACI) specially the Slump and Temperature tests which can immediately and effectively detect deviations in the quality of concrete mixtures.

5. Station of testing the hardened concrete by taking cubes of concrete for the compressive strength testing.

6. Suggested station of inspection 'during the casting process' to assure high production for both specimens and hardened concrete. This procedure should be applied to increase care and protection for each concrete and cubes by allocating particular inspectors and engineers from Quality Improvement Department and Resident Eng. Office to carry out periodical inspection.

8.2.2 Devices and Equipments

All devices and equipments used for examination and inspection must be 'calibrated' periodically, to prevent any deviation in their performance form ever getting out, by taking some procedures like: sending them to a third-party authorized to conduct calibration, providing appropriate environmental conditions for storage, and documenting all the information in the achieve.

8.2.3 Documentation

Document everything by adopting an electronic documentation system depending on computer and manual documentation by hand; which include all kinds of reports such as: purchase orders, quality reports (daily, weekly, and annually), supplier evaluation reports; results of testing, and progress reports.

The responsibilities of 'processes control' stages must be executed and handled by:

1. Examination and Inspection Division.
2. Documentation Division.
3. Stores Division.
4. Quality Improvement Department.

8.3 Output Control (FISH Cycle)

This stage is adopted the sequential 'FISH processes cycle', which stands for Focus, Improve, Sustain and Honor; to strengthen the suggested improvement system as described in the following steps:

8.3.1 Focus on both Reports and Product Delivery

This first step aims at: First, narrowing the focus on performance control reports that issued by Quality Improvement Department to provide top-management with fairly broad range of outputs. Mainly, performance control reports aid managers by measuring deviations from standard plans and evaluating the actual performance according to the results of testing concrete mixtures and raw materials which should be subjected to audits and analysis by members of Quality Improvement Department to prepare recommendations for the corrective actions.

Second, focusing on service by making plans to the way the product should be delivered to the customers.

8.3.2 Improve Performance

This second step seeks to make corrective actions that suggested by members of Quality Improvement Department after fully agreement of top-management.

In this step, some methods such as brainstorming, benchmarking, and quality circles might be used to generate and come up with new ideas that lead to the right corrective/preventive actions. Therefore, the following two methods are recommended to generate ideas:

1. Quality Circles: by creating a work group usually consists of (5-10 persons): one person from Six Sigma Division as a chairman of circle (president), one person of each Design, Examination and Inspection, and Documentation divisions besides foreman and worker; who met periodically (an hour a week) to discuss quality issues, the progress of improvement measures, corrective actions and find appropriate solutions. They often use statistical tools.

2. Establish a system to share information with employees: by encouraging employees to speak out against policies that inhibit quality; and to submit their suggestions through the suggestion box; then, let them know that their suggestions are appreciated; next, reward them appropriately if the suggestion was acceptable and worked; or explain the reason if the suggestion was not feasible.

8.3.3 Sustain the Improvement

One of the most places where people fail down is actually sustaining the improvement whereby changes in the process cannot be detected with naked eyes, but with control charts and histograms it can. Therefore, it is necessary to teach employees how to use statistical process control SPC charts to monitor, manage and maintain the performance by training them how to use these tools.

8.3.4 Honor the Work Team

It is significant to motivate the team members to be the owners of their work and strive for their own specific goal regarding their tasks beside the cooperation toward the common goal and overall success of the project. This can be done by providing health insurance, social security beside increasing allocations and monetary bonus or by giving financial loans to those who submitted distinct jobs.

Fig. 9 pictures the practical side of this research in a flow chart.

9. Conclusions and Recommendations

Conclusions are presented next as a result of field study and DMAIC cycle. According to these conclusions, the research recommendations have been discussed to improve the quality of concrete production by implementing Six Sigma DMAIC methodology.

9.1 Conclusions

1. The current process performance for the quality of concrete works in the case study are: 2.41 sigma level, 81.89% quality yield, 18.11% non-conformance production and 181,070 DPMO which are considered too bad as compared with the current global competition.

2. Al-Rasheed Company has not had clear policy working toward improving quality of concrete production; and suffers from lack of interest in the quality, because it believes that controlling quality costs too much.

3. The absence of specialized departments for managing quality with a task of auditing processes, starting from the early stages of production to the end. Al-Rasheed Company even has not established 'Quality Department' in its organizational structure.

4. Decision-making in Al-Rasheed Company depends on experience and position instead of facts on the ground, despite facts are considered the primary tributary of decision-making in modern systems.

5. Al-Rasheed Company is not performing the testing of fresh concrete besides, limited

6. of examination and testing of the received raw materials from provision sources.

7. Six Sigma organization structure can be adopted with some modification to be in various divisions and departments in company, like replacing the ideal teamwork of Six Sigma (master black belts, black belts, green belts, etc.) by members of either quality circle or proposed Quality Improvement Department.

9.2 Recommendations

1. Any organization that wants to improve their quality of concrete mixture can use DMAIC cycle and the suggested improvement system; then, start by giving personnel a brief introduction on modern management techniques of quality control because they are the base of Six Sigma.

2. Adopting the predictive and preventive maintenance instead of the remedial maintenance can reduce occurrence of defects and breakdowns.

3. Creating Quality Circles to provide corrective and preventive actions taking into consideration information that comes from employee suggestion box.

4. Al-Rasheed Company should start building up an electronic documentation system by using computers to document reports and testing results etc.
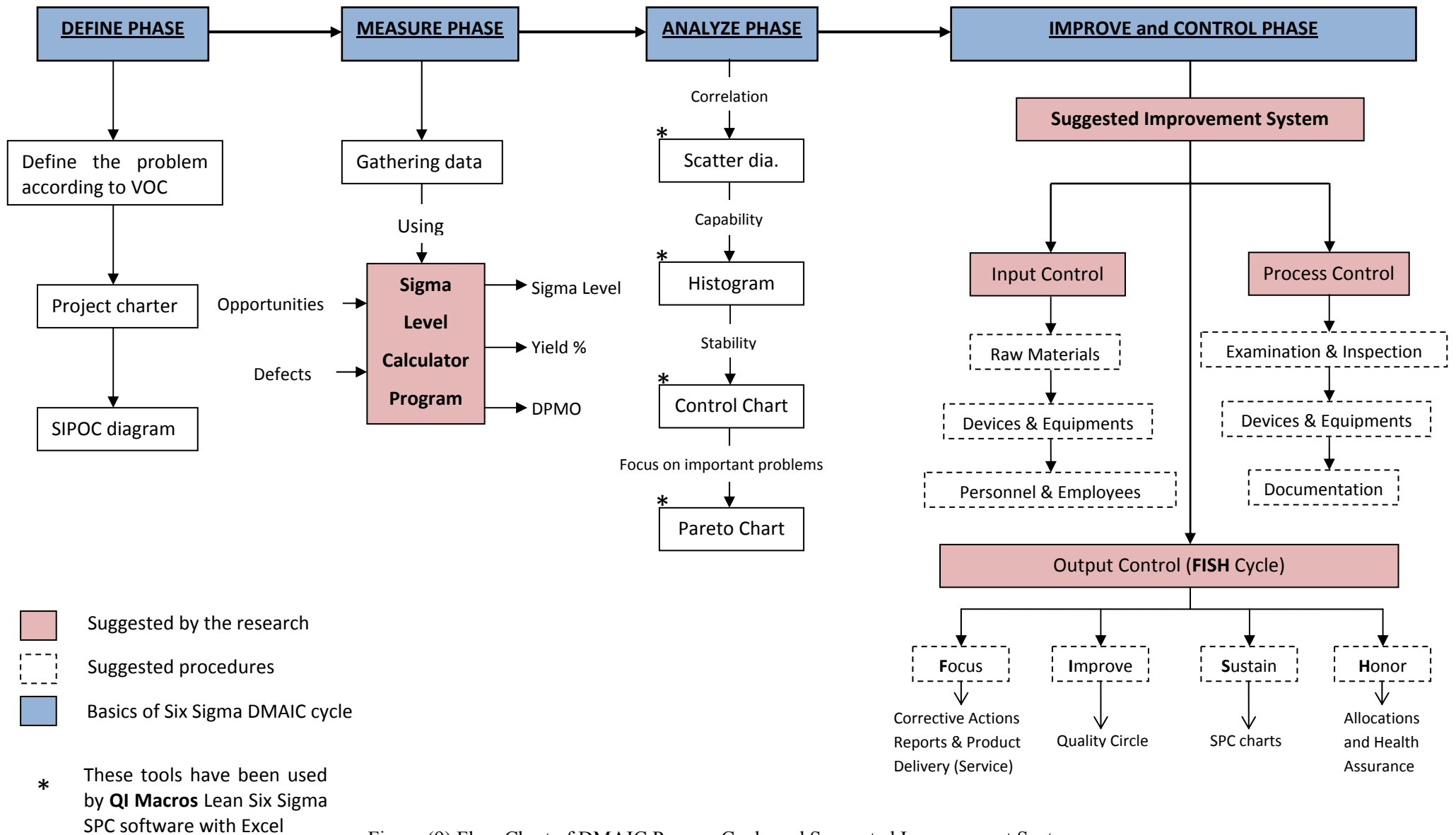
| DEFINE PHASE | → | MEASURE PHASE | → | ANALYZE PHASE | → | IMPROVE and CONTROL PHASE |

DEFINE PHASE

Define the problem according to VOC

Project charter

SIPOC diagram

MEASURE PHASE

Gathering data

Using

Sigma Level Calculator Program

Opportunities →
Defects →

→ Sigma Level
→ Yield %
→ DPMO

ANALYZE PHASE

Correlation

* Scatter dia.

Capability

* Histogram

Stability

* Control Chart

Focus on important problems

* Pareto Chart

IMPROVE and CONTROL PHASE

Suggested Improvement System

Input Control

Raw Materials

Devices & Equipments

Personnel & Employees

Process Control

Examination & Inspection

Devices & Equipments

Documentation

Output Control (**FISH** Cycle)

Focus
Improve
Sustain
Honor

Corrective Actions Reports & Product Delivery (Service)

Quality Circle

SPC charts

Allocations and Health Assurance

Suggested by the research

Suggested procedures

Basics of Six Sigma DMAIC cycle

* These tools have been used by **QI Macros** Lean Six Sigma SPC software with Excel

Figure (9) Flow Chart of DMAIC Process Cycle and Suggested Improvement System

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Shared Congestion Detection: A Comparative Study

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Abstract:

Most Internet-tomography problems such as shared congestion detection depend on network measurements. Usually, such measurements are carried out in multiple locations inside the network and relied on local clocks. These clocks usually skewed with time making these measurements unsynchronized and thereby degrading the performance of most techniques. Recently, shared congestion detection has become an important issue in many computer networked applications such as multimedia streaming and peer-to-peer file sharing. One of the most powerful techniques that employed in literature is based on Discrete Wavelet Transform (DWT) with cross-correlation operation to determine the state of the congestion. Wavelet transform is used as a de-noising tool to reduce the effects of both clock skew and queuing delay fluctuations on the decision of congestion type. Since, classical Discrete Wavelet Transform (DWT) is not shift-invariant transform which is a very useful property particularly in signal de-noising problems. Therefore, another transform called Stationary Wavelet Transform (SWT) that possesses shift-invariant property is suggested and used instead of DWT. The modified technique exhibits a better performance in terms of the time required to correctly detect the state of congestion especially with the existence of clock skew problem. The suggested technique is tested using simulations under different environments.

Keywords: shared congestion, clock skew, shift invariant, cross correlation, soft-threshold operation.

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Introduction

Congestion control is the mechanism that was widely credited with the stability of the service of the internet. Without such mechanism, internet or any other network cannot be survived. In the first generation of internet services that mostly consist of file transfers, congestion control mechanisms are applied per flow without any feedback from the other flows that share the resources of the network. To these services, it is considered adequate.

With the emerging of new services that need a lot of bandwidth and more sensitive to network delay and packet loss, applying congestion control techniques per flow may lead to service degradation. And therefore, the principle of cooperation congestion control is appeared. This concept exhibits a better performance than the older techniques that control the congestion for each flow alone.

The concept of congestion control cooperation is very simple and can be comprehended from the following real situation. Car traffic in any crowded city can be used as a good example to demonstrate the concept. If the car drivers are very selfish and aiming in any method to reach their destinations, without caring of the others, the jam will be terrific, especially in the intersections of the main roads (routers in our problem). However, if the drivers are cooperated between themselves and listen to the instructions of the traffic men, the situation will be better. As a result, the movement of cars will be smoother than before and the jam condition will be of less severity. This is because, the resources are limited and the users of those resources are unlimited. Therefore, the cooperation between users in exploiting the resources decreases the hardness of the situation and enhances the performance.

The same scenario exists in computer networks. Therefore, the cooperation means that the decision is taken according not only to the condition of the flow but from all the flows that share the resources. Hence, the detection of resource sharing especially in the existence of congestion is a significant issue that enhances the performance of the network. The information of shared congestion detection can be used to change the path of packets or to modify the topology of the network in overlay systems.

In general, the operation of inferring shared congestion depends on the feedback information of link delay or packet loss rate or both. Previous works exhibit the robustness of methods that rely on link delay over the methods that depend on packet loss [Rubenstein 2002]. One of the most powerful methods that depend on the delay of the packets as a measure to detect shared congestion is the method presented in [Kim 2008]. The method uses a digital signal processing technique to extract the required information from link delay measurements and uses cross-correlation coefficients to estimate the type of congestion. The method uses discrete wavelet transform as a de-noising tool to isolate the useful information from the delay of the packets and deliver this information to the cross-correlation function.

There are two factors that affect the output of cross-correlation, and thereby, the process of shared congestion detection. These effects corrupt link delay measurements and mislead cross-correlation function. The first factor is the queuing delay fluctuations. This factor is mainly due to the random behavior of the buffers that exist in the routers. The second factor is the effect of clock skew that makes link delay measurements out of synchronization.

To get rid of all these effects, the measurements should be de-noised by threshold the wavelet detail coefficients. However, DWT is not shift invariant transform. Shift variant property means that there is no simple relationship between wavelet coefficients of the signal and those of the delayed version of it [Pesquet 1996]. Therefore, clock skew problem could cause false detection. That is, clock skew might mislead cross-correlation function and change the condition from shared to independent congestion. Therefore, a modification to the technique used in [Kim 2008] is suggested to completely remove the effect of clock skew.

Recently, Stationary Wavelet Transform (SWT) is used successfully in the literature especially in signal de-noising, image de-noising and signal detection [Zikov 2002],[Brychta 2007],[Solbo 2008],[Hai 2009], and [Kubinyi 2011]. The main advantage of SWT is its shift invariant property [Lang 1996]. Using SWT instead of DWT to detect shared congestion has revealed a better performance especially with the existence of clock skew problem, as we will see in the simulation results. The only drawback of SWT

is its computation complexity of order N logs (N) compared to only N for DWT, where N represents the number of samples.

Shared Congestion Detection Using Cross-Correlation Coefficients:

Fig.1 shows the network topology that shared congestion is mainly happened. The link(s) between nodes s and t is (are) shared. To detect shared congestion, packets will be sent with time stamps from node xt to the node xr. At node xr the packets are again time stamped and resent to node xt. For each packet, the difference between the two time stamps represents the time of the journey (time delay). The same thing is done for the two nodes yt and yr. At the end of the experiment, two delay sequences x and y are obtained for the two paths.

Then after, using the cross-correlation function of eq. (1), the condition of the network could be determined [Kim 2008]:

$$XCOR = \frac{\sum_{i=1}^{n}(xi - \bar{x})(yi - \bar{y})}{\sqrt{\sum_{i}^{n}(xi - \bar{x})^2 \sum_{i}^{n}(yi - \bar{y})^2}} \qquad (1)$$

Where: n represents the length of the sequences x and y; $\bar{x}$ and $\bar{y}$ represent the mean values of x and y, respectively.

The key idea behind using cross-correlation coefficient in detecting shared congestion returns to the fact that says; packets that pass through the same congested points possess similar time delay and loss rate patterns [Rubenstein 2002].

For network topology used in this paper, the measured delays consist of two parts. The 1st one is due to packet passing through the shared link between nodes s and t. The other is due to packet passing through the unshared links.

The main property of cross-correlation function, its value is dominated by the most dynamic part of the delay sequence [Kim 2008]. Three cases could happen. If the traffic is light (no congestion in all links), the pattern of the delay sequences has uncorrelated noise-like spikes with

small delay values as shown in **Fig.2**. And, the value of XCOR is around 0.5. This case was not taken into consideration in [Kim 2008]. Neglecting this case could cause false decisions, since; the value of XCOR is very near to the selected threshold value that distinguishes shared congestion from independent one.

If congestion happens in the links between nodes s and t, the delay sequences are highly correlated with pulse like patterns of large amplitudes as shown in **Fig.3**. Therefore, XCOR value approaches 1. If the congestion happens in the unshared links, the pattern of the delay sequences are consist of both pulse-like spikes with large amplitudes and noise-like spikes with small amplitudes as shown in **Fig.4**. It is clear from the figure that the two delay sequences are out of phase and uncorrelated. Hence, XCOR value approaches 0.

Stationary Wavelet Transform (Swt):

One of the drawbacks of the Discrete Wavelet Transform (DWT) is being a shift-variant transform. Shift-variant means that the transform of the delayed version of the signal is not linearly related to the transform of the original signal. Shift-invariant property is very important in many applications such as signal de-noising, image de-noising, signal detection and function estimation.

In normal DWT, the signal of length N is convolved with a LPF h and a HPF g. Then, the output of each filter is down sampled (decimated) by 2 to produce two sequences of N/2 length. One sequence represents the approximation coefficients (LPF branch) and the other represents the detail coefficients (HPF branch). The relation between the filters g and h defines what is called Quadrature Mirror Filter (QMF) [Vetterli 2007]. These coefficients represent first level decomposition of the original signal. To obtain 2nd level coefficients, the approximation coefficients of the previous level (1st level) is convolved again with the same filters g and h to get detail and approximation coefficients of the 2nd level (of length N/4 each). Similarly, detail and approximation coefficients could be obtained for the levels 3, 4, 5, etc.

The decimation operation is necessary to get a non-redundant representation of the signal. But the cost is losing the shift-invariant property of the DWT. Researchers made several

Modifications to the classical DWT to regain shift-invariant property. One of the most powerful algorithms is the Stationary Wavelet Transform (SWT) or sometimes called Shift Invariant Discrete Wavelet Transform [Nason 1995].

The main difference between DWT and SWT is that the signal after convolution with g and h filters is not down sampled by 2. Instead, the filters g and h are up sampled by 2 (starting from the 2nd level). The result of that, the length of both detail and approximation coefficients is the same as the length of the applied signal. In other words, the length of the coefficients of the 1st level decomposition is twice the length of the original signal. Therefore, the signal is of redundant representation. Hence, SWT is sometimes called Non-Decimated Discrete Wavelet Transform. This redundancy preserves shift-invariant property. The cost is increasing the computational complexity and losing the orthogonally of the transform. Losing orthogonally means that the inverse SWT is not unique and could be evaluated using all decimation combinations and then averaged [Nason 1995]. **Fig.5** below gives a schematic view of DWT and SWT.

Signal De-Noising Using Non-Linear Threshold Operation:

Any signal de-noising problem can be stated mathematically as follows:

$$\bar{x}(n) = x(n) + e(n) \qquad (2)$$

where n is an integer number, $x(n)$ is the noise-free signal, $\bar{x}(n)$ is the measured (corrupted) signal, $e(n)$ is the noise.

In literature, many techniques are used for de-noising purposes. One of the most known methods is the non-linear threshold operation. Threshold operation could be employed through soft or hard threshold operation. In this work, soft threshold is employed, since; this technique guarantees smoothness of the de-noised signal to the same degree of the smoothness of the original signal [Donoho 1995].

Soft threshold operation is performed on detail coefficients only as follows: If the coefficients are less than some threshold value,

The coefficients are killed to zero; otherwise, the coefficients are shrunk by the value of the threshold. The following relationship explains soft threshold operation mathematically [Donoho 1995]:

$$d_T = \begin{cases} d - T & if\ d \geq T \\ d + T & if\ d \leq -T \\ 0 & if\ |d| < T \end{cases} \qquad (3)$$

Where T is the threshold value; d_T represents the detail coefficients after threshold.

There are many approaches to determine the value of the threshold T. In this work, the following equation is used to estimate the threshold value [Donoho 1995]:

$$T = \sqrt{2 \times \epsilon \times log_e(N)} \qquad (4)$$

Where N is the number of samples and ϵ is the noise variance.

Simulation and Results:

At the beginning, simulations are carried out on the 3-node network topology shown in **Fig.6** using network simulator NS2. For comparison purposes, the experiment setup is similar to that in [Kim 2008]. The bandwidth of each link is 1.5 Mb/s. The propagation delay is chosen randomly between 20 and 30 msec for each simulation. The background traffic is a pareto ON-OFF constant bit rate (CBR) flow with a pareto shape parameter of (1.2). The average ON and OFF times are 0.2 and 3 sec, respectively. CBR rate is selected uniformly between 20 Kb/s and 40 Kb/s for each simulation. Therefore, the level of congestion could be controlled through the number of CBR flows on each link. The duration of each simulation is 100 sec. To acquire the delay sequences, UDP probe packets are sent at rate of 10 Hz for duration of 100 sec. Also, the bases functions used in denoising are db6.

A. Shared Congestion Detection Experiment:

To simulate shared congestion state, background traffic of 100 CBR flows is initiated on the shared link and 60 CBR flows on the other links. The simulation is repeated for 500 times. **Fig.7** depicts XCOR values of the de-noised delay

sequences using DWT and SWT. These values represent the average of the 500 simulations. It is clear from the graph that XCOR with SWT is faster than XCOR with DWT. XCOR-SWT needs less than 2 sec to reach the correct decision. Whereas, XCOR-DWT technique requires no less than 100 seconds to reach the same value of cross-correlation of XCOR-SWT.

Furthermore, to prove the validity of the proposed technique, simple mathematical calculations would be used. The former technique needs about 10 seconds to correctly detect shared congestion as stated in [Kim 2008]. This means, about 100 probe packets are needed to achieve the task. Since the computational complexity of DWT is proportional to the number of packets, therefore, evaluating DWT requires a computational power of order 100 operations. Whereas, the modified technique that depends on SWT needs about 1.6 seconds (only 16 probe packets) to detect correctly shared congestion. Hence, the computational power of the modified technique is of order 16 ×Log (16) = 19 only. In addition, it is clear that the evaluation of cross-correlation coefficient for 16 packets needs fewer operations than for 100 packets.

B. Independent Congestion Detection Experiment:

To simulate independent congestion state, background traffic of 60 CBR flows is initiated on the shared link and 100 CBR flows on the other links. Also, the simulation is repeated for 500 times. **Fig.8** draws XCOR averaged values of the de-noised delay sequences using DWT and SWT.

It is obvious; the behavior of XCOR-SWT in detecting independent congestion is comparable to XCOR-DWT especially for the first 10 seconds as expected. Since, the delay sequences of the two paths are completely uncorrelated. That is, at independent congestion, the noise has nothing to do with time delay measurements and even if the sequences are not de-noised, XCOR values approach zero at the same performance, approximately. Although, cross-correlation coefficient values of DWT-de-noised sequences are more closer to zero than those de-noised by SWT. Because, shift-invariant property of SWT has an averaging effect on the data. Consequently, the de-noised delay sequences are little over-smoothed and, thereby, are more correlated than

before. This makes cross-correlation coefficient values of SWT-de-noised sequences are somewhat greater than those of DWT-de-noised sequences. Also, the figure shows that XCOR coefficients of the SWT–de-noised sequences are more stable than the coefficients of the DWT–de-noised sequences, because, the bases functions of DWT are more time-varying than those of the SWT.

C. Shared Congestion Experiment With Clock Skew:

To evaluate the effect of clock skew on the decision of the type of congestion, the following is done: One of the delay sequences is shifted by an offset δt with respect to the other delay sequence. δt represents the time deviation between the two clocks on which time delays are sampled. Then, only the overlapped portion of the two sequences is used to identify the state of the congestion. This procedure is applied on the delay sequences that are obtained from the **"shared congestion detection experiment"**. **Fig.9** draws the behavior of the two techniques (XCOR-DWT and XCOR-SWT). In this graph, the usefulness of time-invariant property of SWT is obvious. The effect of clock skew on XCOR-SWT is negligible compared to the performance of XCOR-DWT.

D. Simulations With More Realistic Topologies:

Computer networks in real life are more complex than the network used in the previous simulations. Therefore, another set of simulations in a more challenged environment should be conducted in order to investigate the robustness of the suggested technique compared to the previous one
.

Practically, most network traffics in the internet are carried out using TCP as a transport protocol. Therefore, the next simulations will include both traffic types; TCP and UDP traffic flows.

Moreover, all the simulations will be achieved in a more realistic network topology that shown in **Fig.10**

D.1 Simulations with TCP Traffics:

The experiment setup consists of the following:

1. Shared congestion case: For each simulation, a link is randomly chosen from the shared links (links 1, 2, & 3) and background traffic of 20

2. file transfer TCP flows is created to cross the intended link. The other unshared links (links 4,5,6,7, & 8) are left idle.

3. Independent congestion case: The shared links are left idle and the non-shared links are traversed by background traffic of a number of TCP flows that is selected randomly from 0 to 20 for each simulation.

In both cases, the simulation is repeated for 500 times. The averaged performance of the suggested technique is depicted pictorially in **Fig.11** and **Fig.12**.

The values on the y-axis represent the "Positive Ratio". This metric will be used to measure the performance of the technique. Positive Ratio could be defined as the ratio of the number of answers indicating shared congestion to the number of experiments [Kim 2008]. This metric will approach to 1 if the experiment involves shared congestion and will approach to 0 in the case of independent congestion. The threshold that would be used to differentiate XCOR values of shared congestion from independent congestion is 0.512[Kim 2008]. **Fig.13** shows the effect of clock skew on the performance of both techniques with TCP flows.

D.2 Simulations with UDP Traffics:

The experiment setup consists of the following:

1. Shared congestion case: In this case, a 100 ON-OFF constant bit rate (CBR) flows is initiated in one of the shared links (slected randomly for each simulation). The number of background traffic flows on the other links is chosen randomly from 31 to 70.

2. Independent congestion case: The shared links are traversed by a number of CBR flows that is chosen randomly from 31 to 70. The other links are occupied by a background traffic of CBR flows of a number selected randomly from 61 to 100.

In both cases, the experiment is repeated for 500 times. **Fig.14** and **Fig.15** summarized the averaged performance of the suggested technique compared to the previous one.

Fig.16 shows the effect of clock skew on the performance of both techniques with CBR flows.

Conclusions:

In this work, a comparison study is made between Discrete Wavelet Transform (DWT) and Stationary Wavelet Transform (SWT) in a signal de-noising problem. These two transforms are used with the Cross-Correlation function to identify the state of the congestion in a network of a known topology. This study reveals that signal de-noising using SWT is more accurate than signal de-noising using DWT. This makes shared congestion detection using XCOR-SWT faster than XCOR-DWT. Therefore, the modified technique pumps the network with fewer probe packets than the former technique. Also, the results shows that signal denoising using SWT is more robust against network dynamics than DWT. This property could be noticed from the different Positive Ratio curves and for both types of traffics.

The main contribution of this work is completely eliminating the effect of clock skew on shared congestion detection. This effect could mislead detection process and might change the state of the network from shared congestion to independent congestion. The only disadvantage of Stationary Wavelet Transform, it consumes more computational power than Discrete Wavelet Transform for the same no. of samples. This drawback is neutralized, since; XCOR-SWT technique detects shared congestion faster than XCOR-DWT, as shown in the results.

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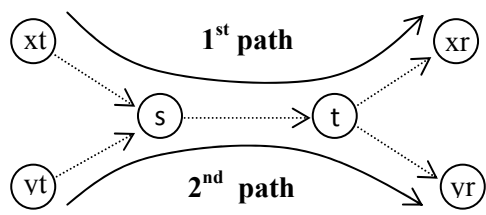
Fig.1: Network topology that is used to study shared congestion.
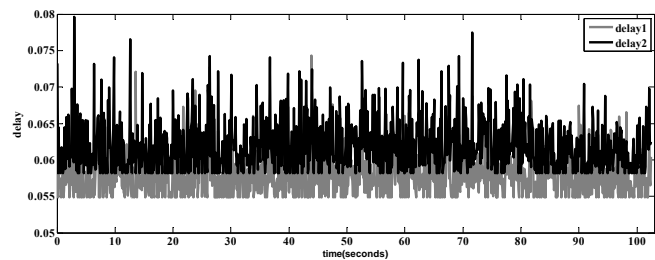
Fig.2: The two link delay patterns when the traffic is light.
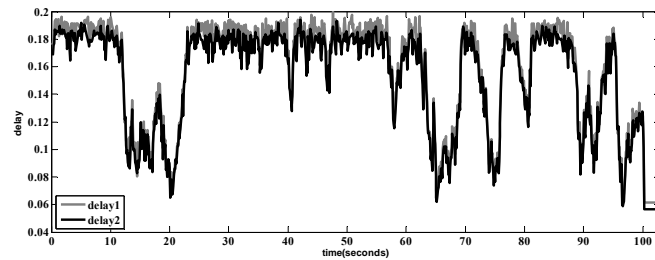
Fig.3: The two link delay patterns with shared Congestion.
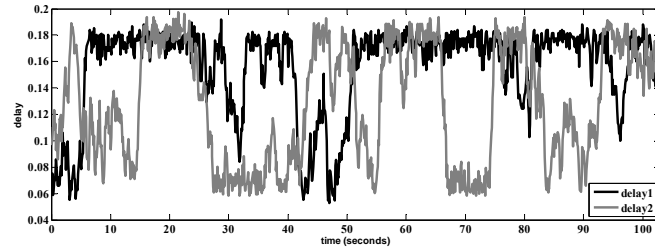
Fig.4: The two link delay patterns with independent congestion.
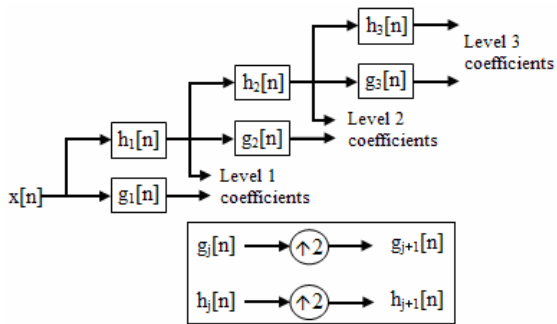
(a) SWT.
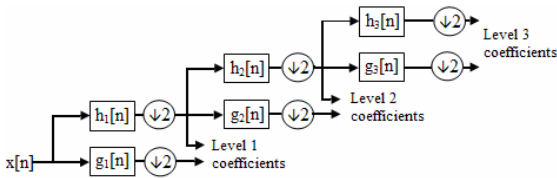
(b) DWT.

Fig.5: Stationary and discrete wavelet transforms [Liu 2007].
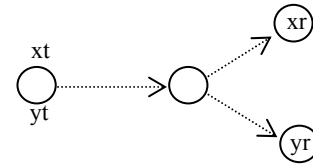
Fig.6: Network topology that is used in the simulation.

XCOR

time(sec)
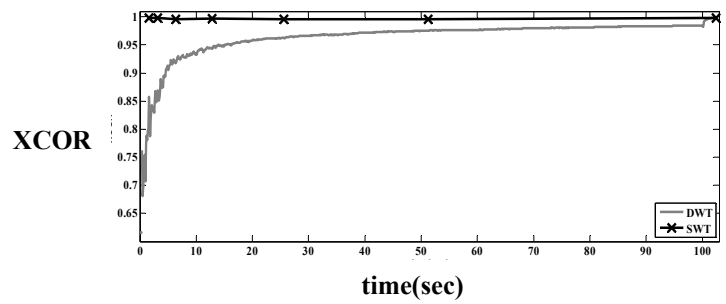
Fig.7: XCOR coefficients of the de-noised sequences using SWT and DWT for the shared congestion experiment.

XCOR

time(sec)
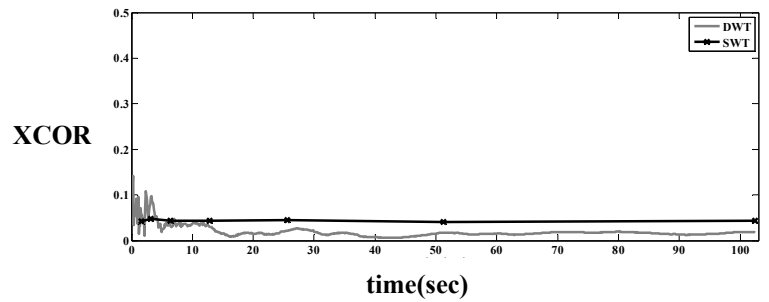
Fig.8: XCOR coefficients of the de-noised sequences using SWT and DWT for the independent congestion experiment case.
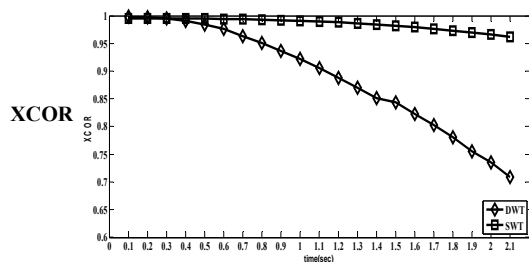
Fig.9: The effect of clocks skew on the XCOR coefficients of both SWT and DWT de-noised sequences.

Fig.10: Network topology with multi-shared links.

Fig.11: Positive ratio for TCP traffic with shared congestion case.
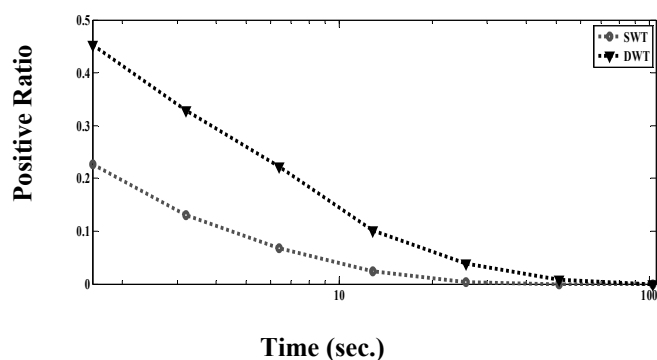
Fig.12: Positive ratio for TCP traffic with independent congestion case.

Fig.13: The effect of clock skews on both techniques for TCP traffics.
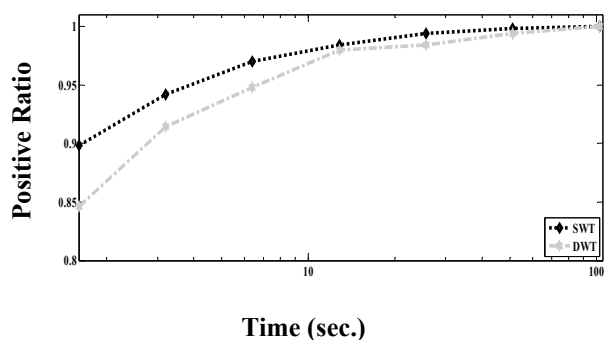
Fig.14: Positive ratio for UDP traffic with shared congestion case.

Fig.15: Positive ratio for UDP traffic with independent congestion case.
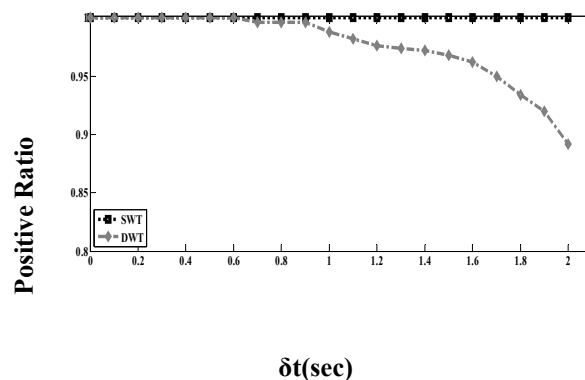
Fig.16: The effect of clock skews on both techniques for UDP traffics.

Design and Implementation of a Vlsm Simulator

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Abstract

Variable-Length Subnet Masks (VLSM), often referred to as "subnetting a subnet", is used to maximize addressing efficiency. The network administrator is able to use a long mask on networks with few hosts, and a short mask on subnets with many hosts. This addressing scheme allows growth and does not involve wasting addresses. VLSM gives a way of subnetting a network with minimal loses of IP addresses for a specific range.

Unfortunately, the network administrator has to perform several mathematical steps (or use charts) to get the required results from VLSM.

In this paper, a simple graph simulator is proposed (using Visual Basic 6.0 Language) to perform all the required mathematical steps and to display the obtained required information (the subnet ID, broadcast ID, usable addresses for sub networks and others). The simulator also includes the ability to draw a suggested network topology that matches the entries.

The implementation of the simulation required only very few entries (IP, prefix and number of subnets).This simulator is useful for students, instructors, and network engineers to analysis and design a VLSM network by providing all required information in simple, fast and easy steps. Moreover, the software draws a full detailed suggested network topology which is considered a helpful tool for the network administrator that he should have.

Keywords: VLSM, IP Addressing, Subnetting, Maximize Addressing Efficiency.

الخلاصة:

الشبكات الفرعية ذات القناع المتغير (variable length subnet mask) عادة نشير بها الى تجزئة الشبكات الفرعية، وهي تستخدم لزيادة كفاءة العنونة. بحيث يتمكن مدير الشبكة من استعمال قناع طويل من الشبكات ذات الاجهزة القليلة وقناع قصير مع الشبكات ذات الاجهزة العديدة. طريقة العنونة هذه تسمح بالنمو للعناوين ولا تتضمن خسارة في العناوين. الشبكة الفرعية ذات القناع المتغير تعطي طريقة لتجزئة الشبكات بأقل خسائر للعناوين لمدى معين من العناوين.

لسوء الحظ ، مدير الشبكة يتوجب عليه القيام بعدة عمليات رياضية (أو استعمال مخططات معينة) للحصول على النتائج المطلوبة من الشبكات الفرعية ذات القناع المتغير.

في هذه الورقة البحثية، نقترح محاكي بسيط مع قابلية رسم للشبكة (باستعمال لغة برمجة Visual Basic 6.0) للقيام بكل العمليات الرياضية المطلوبة وعرض النتائج المستخلصة (عنوان الشبكات الفرعية وعنوان البث لكل شبكة فرعية و بداية ونهاية عناوين الأجهزة المستخدمة في كل شبكة فرعية وغيرها). المحاكي ايضاً يتمتع بالقدرة على رسم مخطط لشبكة مقترحة والتي توافق المدخلات.

تصميم المحاكي يتطلب عدد قليل من المدخلات مثل (رقم الشبكة و ملحق الشبكة وعدد الشبكات الفرعية). يعتبر هذا البرنامج مهم للطلبة، للمدرسين ولمهندسي شبكات الحاسبات لتحليل ,وتصميم الشبكة الفرعية ذات القناع المتغير عن طريق توفير كل المعلومات المطلوبة بخطوات بسيطة وسريعة وسهلة. أضافة لذلك ، البرنامج يرسم طوبوغرافية الشبكة بكافة التفاصيل والتي تعد أداة مفيدة لمدير الشبكة يتوجب عليه أمتلاكها.

Introduction
Classical IP Addressing Scheme

An IP address consists of 32 bits of information. These bits are divided into four bytes; it is structured or hierarchical address, the advantage of this scheme is that it can handle a large number of addresses, namely 4.3 billion. Subdividing an IP address into a network and node address is determined by the class designation of one's network. Fig. 1 summarizes the three classes of networks. [4]
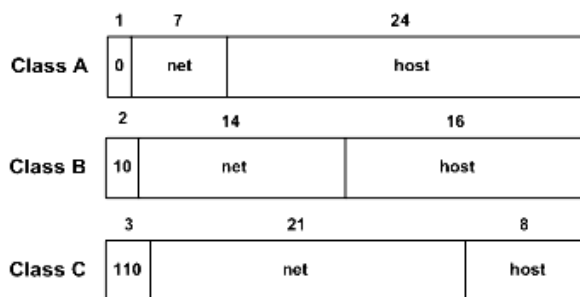

Fig. 1: Summary of the three network classes

The designers of the Internet decided to create classes of networks based on network size. For the small number of networks possessing a very large number of nodes, they created the rank Class A network. At the other extreme is the Class C network, which is reserved for the numerous networks with a small number of nodes. The class distinction for networks between very large and very small is predictably called the Class B network. Every machine on the same network shares that network address as part of its IP address. The node address is assigned to, and uniquely identifies, each machine on a network. This number can also be referred to as a host address. Table 1 shows the more details about three classes of networks.[4]

Fixed-Length Subnet Masks (Subnetting)

As discussed in previous section, the IP address space features a two-tier hierarchy in which each address consists of a network address and a host address within its 32-bit structure. Such flatness distinctly limits scalability in a number of ways. Perhaps the most confining limitation is that the address space assumes that all networks fit into one of just three different sizes of networks small, medium, and extremely large.

For example each class B network address contained 16 bits in the host portion, it controlled 65,534 addresses. (Remember, 2 addresses were reserved for the network and broadcast addresses).

Only the largest organizations and governments could ever hope to use all 65,000 addresses. The IP address space was tremendously wasted.

IP address space was depleting rapidly, for more efficient use of IPv4 address space, creating a third tier for identifying subnetwork addresses is a relatively straightforward concept that involves "borrowing" bits from the host portion of the address. These bits are used to create subnetwork addresses as an extension of the network address. In other words, smaller networks can be created and uniquely addressed from larger networks and network address spaces.

Subnetting a class A address space would have the tremendous benefit of making more efficient use of the available pool of addresses. Subnetting a class C network address space with just 254 total available host addresses makes quick aware of the finite nature of those addresses. Logically, the more borrowed bits from the host field to create subnets, the fewer bits that remain for the identification of hosts. Fig. 2 shows the format addresses when subnetting. [3]
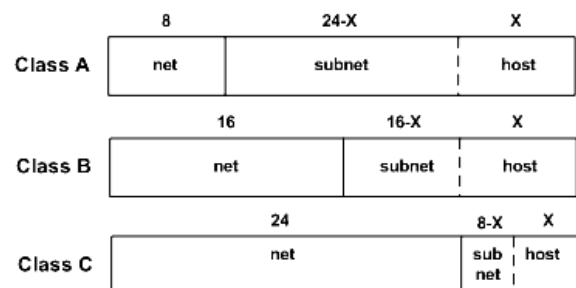

Fig. 2: Address formats when subnetting is used [6]

The Subnet Mask

A subnet mask is a 32-bit binary number; a subnet mask is structurally similar to an IP address. However, a subnet mask does serve an important function: It is used to tell end systems (including routers and hosts in the LAN) how many bits of the IP address's host field have been borrowed to identify the subnet. The bits in the mask that identify the network address, as well as the subnet address, are set to 1s. The remaining bits, which are used for host addresses within each subnet, are set to 0s.

Table 2 shows the dotted-decimal and dotted-binary forms of default subnet masks for class A, B, and C. Table 3 shows the dotted-decimal and dotted-binary forms of subnet masks

that are permissible when subnetting a class C address. [3]

Extended Network Prefix

It is important to note that the borrowed bits are always the leftmost bits in the host field. Thus, the subnet address is numerically contiguous with the network address. Together, they form the extended network prefix. The remaining bits are used for host identification. [3]

The extent of the increase in network bits depends on the number of required subnets and the number of required hosts on each subnet. Table 4 and Table 5 show Prefix Length and possible ways of subnetting class B and C networks. [2]

Variable-Length Subnet Masks

Subnetting, in general, was designed to enable more efficient use of address space by permitting class-based network address blocks to be subdivided into smaller address blocks. Yet the way subnetting was originally implemented was far from efficient. Source of waste and inefficiency with FLSM, There was one size of mask for all subnets. Implementing FLSM actually wastes IP addresses. [3]

For example, the serial link between two routers, as shown in Fig. 3, shares the same network to talk. Two IP numbers are required, one for each serial interface, unfortunately, eight-bit subnet mask are available (i.e., 255.255.255.0), so 252 IP addresses are wasted of the 254 available numbers on the subnet. One possible solution to this dilemma is to use Variable-Length Subnet Masks (VLSMs).
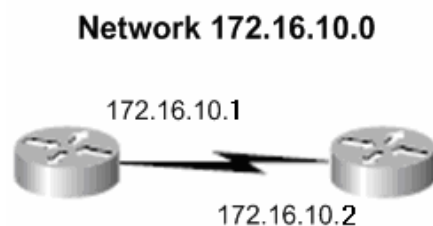
Network 172.16.10.0

Fig. 3: IP address example

As the name suggests, with Variable-Length Subnet Masks, different subnet masks for different subnets are available. So, for the serial link in this example Fig. 3, the network address is 172.16.10.0/30 with subnet mask of 255.255.255.252.by calculation of IP addresses in this network one can see that only two host bits are considered, as shown in Table 6. [3]

Therefore, this subnet mask will give only two host IPs ($2^2 - 2 = 2$), which is exactly what is required for this serial link. [5]

Implementing Vlsm Networks

To create VLSMs quickly and efficiently, there is needs to understand how block sizes and charts work together to create the VLSM masks. Table 7 shows the block sizes used when creating VLSMs with Class C networks. For example, if 25 hosts' subnet is required, then it belongs to a block size of 32. Also, if 11 hosts' subnet is required, then it belongs to a block size of 16. Moreover, if 40 hosts' subnet is required, then it belongs to a block size of 64. [4]

The next step in creating a VLSM network is by using the VLSM worksheet or chart. The reason of using this table and chart are to prevent overlap networks.

Visualizing Subnets Using a Vlsm Chart

The VLSM chart is the method used to visualize the breakdown of subnets and addresses into smaller sizes. By shading or coloring in the boxes one can easily break up subnets without overlapping addresses. Each sub-subnet can be adjusted to the correct size needed. [1]

Example

A company has IP address range of 192.168.16.0/24 and this company wants to create four subnets (20, 60, 120, 2 hosts/subnet) as shown in Fig. 4.

To solve such issue, a VLSM method should starts with the largest groups (hosts/ subnet), i.e. decently (120, 60, 20, 2). Then by using the VLSM chart (shown in Fig. 5) one can distribute the required block size of each subnet into the right size by shading the required area in chart. Shading an area reserves it from another subnet placement. After distributing all subnets the resulted network will be as shown in Fig. 4.

Software Implementation Of The Vlsm Simulator:

This section presents the software implementation of the VLSM Simulator that had been built from mathematical operation which discussed in previous sections. VLSM Simulator contains more than one window to display its operation; this section presents and explains the work of VLSM Simulator's windows and the relationship between these windows.

The Main Window of the VLSM Simulator:

Fig. 6 shows the main window of the VLSM Simulator, which consists of six parts,

Part1:- For entering the desired IP address to be analyzed, this part will determine the following:-
1- Default network prefix.
2- Network IP address that the desired IP address belongs to.
3- Broadcast IP address of this network.

Part2:- For displaying some attributes on the desired IP address, these attributes include:-
1- Class of the IP address (A, B or C).
2- Type of the IP address in the network (Host, Network or Broadcast IP address).
3- Category of the IP addresses (private or public IP address).
4- The usable host range before sub netting.

Part3:- For entering the needed number of subnets (default subnet equal to one), and for entering the number of hosts at each subnet.

Part4:- For displaying the calculated sub netting information, which includes:-
1- The lost IP addresses duo to sub netting (network IP address and broadcast IP address at each subnet).
2- The used IP addresses after sub netting (total reserved IP addresses for all subnets).
3- The number of remaining (not used) IP addresses.

Part5:- For generating VLSM topology table and drawing a suggested topology map, which includes each subnet and subnet's IP address ranges.

Part6:- For displaying the topology table which includes the required information needed by the network administrator to build the network.

Entering the IP Address and Generating VLSM

When the user enters the desired IP address and prefix of the network, the software will create the network and Broadcast IP addresses which the desired IP address belongs to. When he enters the number of subnets, the software will create a number of boxes equals to number of subnets. The next step is that each box must be filled with number of host required in each subnet.

The "Generate VLSM" button will be activated after entering the above parameters. Clicking this button, resulting in displaying a table that includes the important parameters about each subnet as shown in Fig. 7 and the flow chart is shown in Fig. 10 . These parameters are network name, Net IP, start IP, End IP, BC IP, prefix, Total hosts, used hosts and remaining hosts.

Draw Topology

One can click on "Draw Topology" button in the main window to draw and display the suggested topology with the least number of routers.

Each router in the suggested topology has at most two fast Ethernet ports and two serial ports. Note that detailed IP information of the network can be enabled or disabled by clicking on check box on the top of the "Draw Topology" window named as "show all networks IPs" command shown in Figs. (8.a) and (8.b).

Survey Questions to Test the Simulator

The simulator was tested by a group of volunteers those were students and were well-trained on VLSM sub netting. Each student was asked to solve four different questions by hand, and then resolve the same questions using the VLSM Simulator. Table 8 shows the required time (in minutes) by each student to answer each question once by hand and then by simulator. Fig. 9 shows a chart which includes the average time by hand compared to the average time required by using simulator.

These questions were selected to be easy to solve and maximum number of routers does not exceed 3 routers with total of 8 subnets to simplify the answering to the students.

The students spent more time in computations. With increasing of questions difficulty, whereas only few extra seconds are added for the simulator to get the same results.

The results do not put in consideration the hand written mistakes that could occur in solutions with hand while using simulator no error occurs in those results.

The students were asked to put only network ID to reduce solving time and no more extra time spent on other important information or the overall sketch.

While the simulator do all the jobs:
- It gives a detailed table contains, subnet ID ,start IP address ,end IP address ,no. of

host per subnet, …etc. See Figs. 7, (8.a) and (8.b).

- It gives full detailed answers with a sub netting table (Fig. 7) and topology sketch of all required subnets and WANs connections as shown in Figs. (8.a) and (8.b).

Conclusions and Features of the Simulator

Many conclusions and features in this software can be noticed in this work, as follows:

1- The software determines the number of lost IP addresses.
2- The simulator validates the entries and prevents the use of incorrect numbers in IP fields (the correct range from 0 to 255).
3- By changing the IP address, the software automatically changes the range of network prefix according to IP class (the range of network prefix for class A is from 8 to 30, for class B is from 16 to 30, and for class D is from 24 to 30). Allowing the decision to the administrator to choose the correct subnet mask and to prevent him from putting incorrect subnet mask.
4- After entering correct IP address and subnet mask, the software automatically calculates the Network IP address and Broadcast IP address, which are needed by the network administrator in his work.
5- The software draws the suggested topology with minimum number of routers.
6- The software prevents adding more subnets incase of exceeding the allowable range of IP addresses.
7- The software prevents adding more hosts in each subnet incase of exceeding the allowable range of IP addresses.

8- After entering the number of hosts in each subnet, the software will descend the order of these subnets automatically. Ordering subnet's hosts from large to small process is required by the VLSM technique.
9- The software creates the topology table which contains the important information of addressing required by the network administrator.
10- The software makes in consideration the waste IPs for WAN links between routers. Therefore; the administrators does not need to calculate the lost IPs. Moreover the software addresses the links completely and adds it to the topology table.
11- The software draws the suggested network with full detailed information for each router's links and subnets.

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Table 1: IP address classes [1]

Address Class	1st Octet Range	1st Octet bits	Net and Host Part of Address	Default Subnet mask	No. of Nets and Hosts/Net
A	1 - 127*	00000000 – 01111111	N.H.H.H	255.0.0.0	128 nets (2^7) 16,777,214 host (2^24-2)
B	128 - 191	10000000 – 10111111	N.N.H.H	255.255.0.0	16,384 nets (2^14) 65,534 hosts (2^16-2)
C	192 - 223	11000000 – 11011111	N.N.N.H	255.255.255.0	2,097,150 nets (2^21) 254 host (2^8-2)
D	224 - 239	11100000 – 11101111	NA (multicast)		
E	240 - 255	11110000- 11111111	NA (experimental)		

*All zeros (0) and all ones (1) are invalid host addresses

Table 2: Default subnet masks

Address Class	Dotted-Decimal Form	Dotted-Binary Form
Class A	255.0.0.0	11111111.00000000.00000000.00000000
Class B	255.255.0.0	11111111.11111111.00000000.00000000
Class C	255.255.255.0	11111111.11111111.11111111.00000000

Table 3: Subnet masks

Borrowed Bits	Dotted-Decimal Form	Dotted-Binary Form
1	255.255. 255.128	11111111.11111111.11111111.10000000
2	255.255.255.192	11111111.11111111.11111111.11000000
3	255.255.255.224	11111111.11111111.11111111.11100000
4	255.255.255.240	11111111.11111111.11111111.11110000
5	255.255.255.248	11111111.11111111.11111111.11111000
6	255.255.255.252	11111111.11111111.11111111.11111100

Table 4: Class B network subnetting

Network Mask	Prefix Length	Subnet Bits	Node Bits	Subnets	Hosts
255.255.0.0	/16	0	16	0 (1 Net)	65534
255.255.128.0	/17	1	15	2	32766
255.255.192.0	/18	2	14	4	16382
255.255.224.0	/19	3	13	8	8190
255.255.240.0	/20	4	12	16	4094
255.255.248.0	/21	5	11	32	2046
255.255.252.0	/22	6	10	64	1022
255.255.254.0	/23	7	9	128	510
255.255.255.0	/24	8	8	256	254
255.255.255.128	/25	9	7	512	126
255.255.255.192	/26	10	6	1024	62
255.255.255.224	/27	11	5	2048	30
255.255.255.240	/28	12	4	4096	14
255.255.255.248	/29	13	3	8192	6
255.255.255.252	/30	14	2	16384	2

Table5: Class B network subnetting

Network Mask	Prefix Length	Subnet Bits	Node Bits	Subnets	Hosts
255.255.255.0	/24	0	8	0 (1 Net)	254
255.255. 255.128	/25	1	7	2	126
255.255.255.192	/26	2	6	4	62
255.255.255.224	/27	3	5	8	30
255.255.255.240	/28	4	4	16	14
255.255.255.248	/29	5	3	32	6
255.255.255.252	/30	6	2	64	2

Table 6: VLSM example

Decimal	255	255	255	252
Binary	11111111	11111111	11111111	11111100

Table 7: Block sizes

Prefix	Mask	Host	Block Size
/25	128	126	128
/26	192	62	64
/27	224	30	32
/28	240	14	16
/29	248	6	8
/30	252	2	4

WAN 0: 192.168.16.224\30

NET 0: 192.168.16.0\25

120 required hosts

NET 1: 192.168.16.128\26

60 required hosts

NET 2: 192.168.16.192\27

20 required hosts

Fig. 4: Desired subnetted network

Fig. 5: Class C VLSM chart

Fig. 6: The main window of the VLSM simulator

Fig. 7: Entering the IP address and generate VLSM
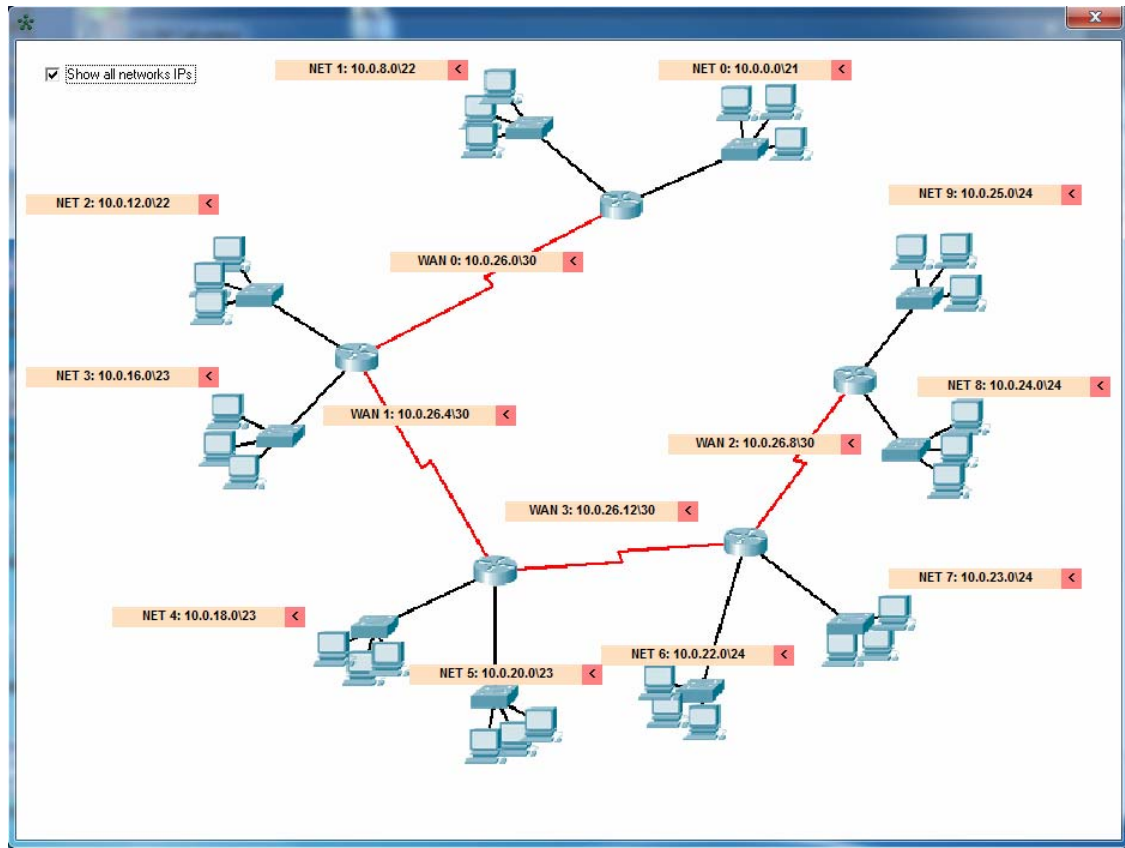
Fig. 8.a: "Draw topology" window with (10 subnets, 4 WAN links)
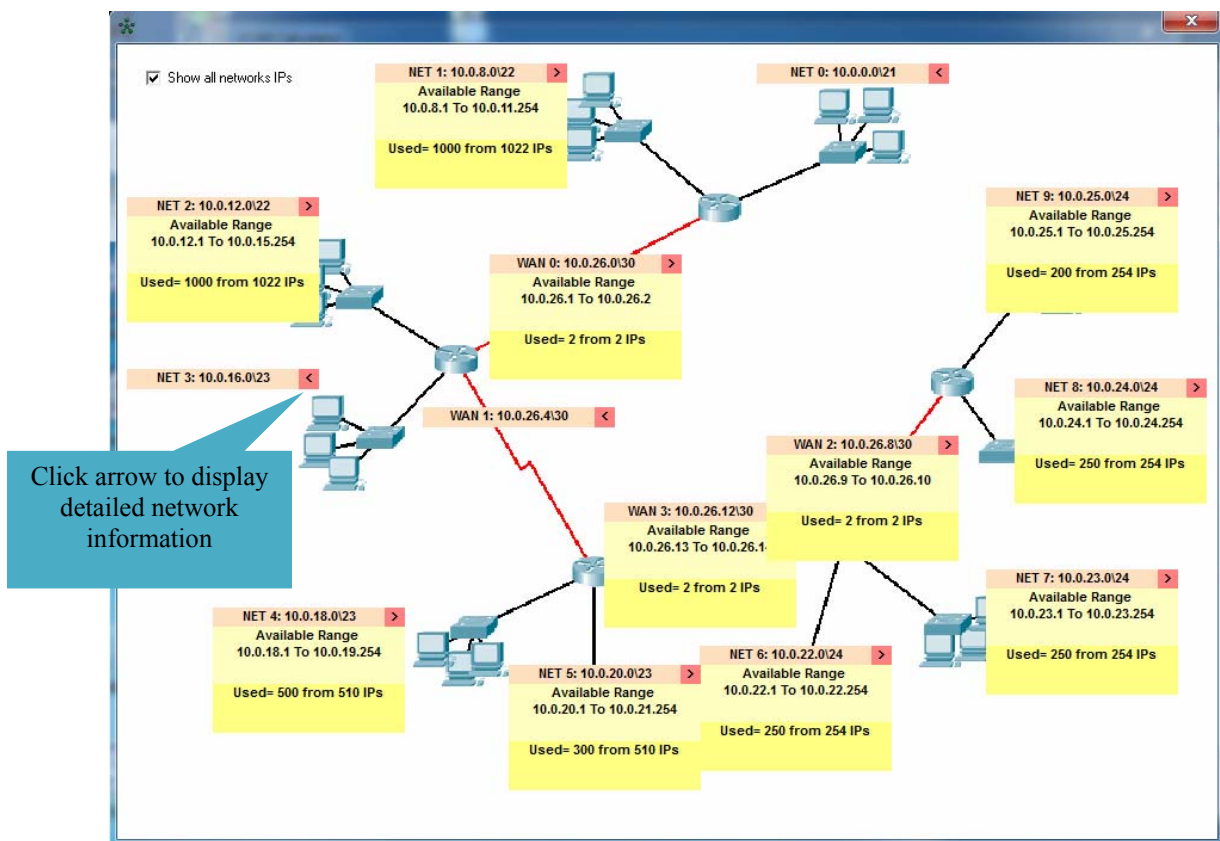
Fig. 8.b: "Draw topology" window with (10 subnets, 4 WAN links)
Shows details by clicking the arrow near subnet's name

Table 8: Students time results for each question (in minutes)

Student No.	Question1		Question2		Question3		Question4	
	hand	*simulator*	*hand*	*simulator*	*hand*	*simulator*	*hand*	*simulator*
1	12	2	5	1	7	0.5	7	0.5
2	9	1	5	1	3	1	4	1
3	15	1	9	0.5	5	1	6	1
4	13	1	5	1	3	1	3	1
5	12	0.5	13	2	17	1	8	2
6	13	1	9	2	8	2	5	2
7	17	1	8	1	6	1	11	1
Average	**13.00**	**1.07**	**7.71**	**1.21**	**7.00**	**1.07**	**6.29**	**1.21**
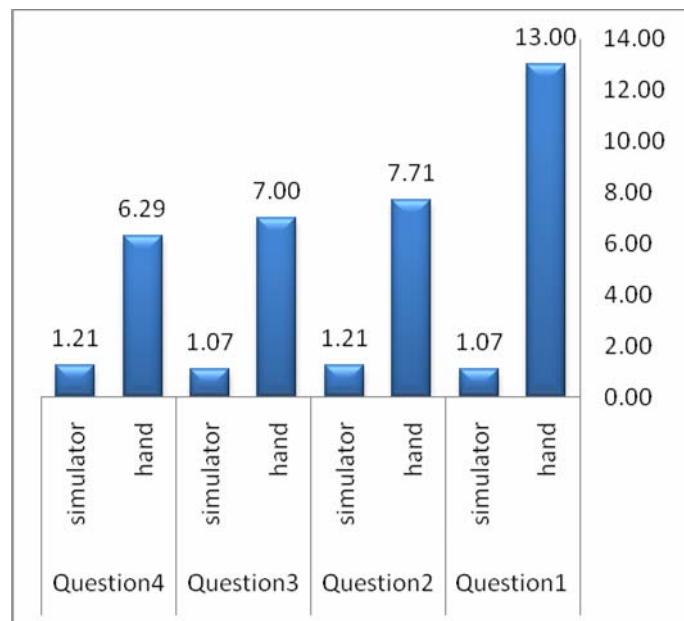
Fig. 9: Chart shows comparison between average student's times for all question result's (in minutes)

Begin

Arrange Subnets according to **number of hosts at each subnet** in descend order (Fig. 6 Part3)

$i=0$

New Net IP address=Network IP Address
(before subnetting as in Fig. 6 Part1)

$i=i+1$

Read number of hosts of *Subnet i*

Calculate n: where
$2^n - 2 >= $ number of hosts of *Subnet i*

Net IP of *subnet i*= New Network IP address.
Start IP address of *subnet i*= Net IP of *subnet i* + 1
End IP address of *subnet i* = Net IP of *subnet i* + 2^n - 1
BC IP address of *subnet i*= Net IP of *subnet i* + 2^n

No. of total hosts per subnet=2^n
Prefix of *subnet i* = 32 - n
Total hosts of *subnet i* = 2^n - 2
Remain hosts of *subnet i*= 2^n – 2 - number of hosts of *Subnet i*

Write information in result's table at record no. *i*
(Fig. 6 part 6)

Is i < no. of subnets?

Yes

No

End

Fig. 10 The flow chart of the generate VLSM process

Sorption of Lead, Zinc and Copper from Simulated Wastewater by Amberlite Ir-120 Resin

By

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Abstract

The presence of heavy metals in the environment is major concern due to their toxicity. In the present study a strong acid cation exchange resin, Amberlite IR 120 was used for the removal of lead, zinc and copper from simulated wastewater. The optimum conditions were determined in a batch system of concentration 100 mg/L, pH range between 1 and 8, contact time between 5 and 120 minutes, and amount of adsorbent was from 0.05 to 0.45 g/100 ml. A constant stirring speed, 180 rpm, was chosen during all of the experiments. The optimum conditions were found to be pH of 4 for copper and lead and pH 6 for zinc, contact time of 60 min and 0.35 g of adsorbent. Three different temperatures (25, 40 and 60°C) were selected to investigate the effect of adsorption temperature on heavy metals adsorption onto Amberlite IR. The equilibrium data were analyzed by the Langmuir and Freundlich isotherms. The thermodynamic parameters such as Gibbs free energy, enthalpy and entropy changes were calculated. Moreover, in order to understand the heavy metal extraction kinetics in the presence of Amberlite IR 120, the ion exchange kinetics was also studied. The ion exchange kinetics data were regressed by the pseudo first-order, second-order models. The results obtained show that the Amberlite IR 120 strong acid cation exchange resin performed well for the removal of lead, zinc and copper.

Keywords: Heavy metals; Simulated wastewater; Sorption; Isotherm; Kinetics; Thermodynamics.
معادن ثقيلة ، فضلات مياه ، امتزاز ، ثبوت درجة الحرارة ، حركيات ، الديناميكا الحرارية.

امتزاز الرصاص والزنك والنحاس من فضلات المياه بواسطة راتنج (Amberlite IR-120)

أ.د. وليد محمد صالح   م. د. حاتم عسل كزار   نوار فلاح حسن

:

(Amberlite   .

(   )   .   IR120)

100   0.45   0.05   120   5   8   1   /   100

4   .   180   .

.   0.35   60   6

° 60   40   25

. Freundlich   Langmuir   .

.

(kinetics)

.   (Amberlite IR120)   .

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1. Introduction

The release of large quantities of heavy metals into the natural environment has resulted in a number of environmental problems. Toxic metals can be distinguished from other pollutants, since they are not biodegradable and can be accumulated in nature. They also cause various diseases and disorders when exceed specific limits (Gode and Pehlivan, 2003 ; Veli and Alyuz, 2007).

Many separation techniques have been proposed for the identification of metals in various samples, including solvent extraction, ion exchange, co-precipitation, membrane process and sorption (Sule and Ingle, 1996; Adria-Cerezo and LIobat-Estelles, 2000; Leinonen and Lehto,2000). Among the heavy metal removal process, ion exchange process is very effective to remove various heavy metals and can be easily recovered and reused by regeneration operation. Ion exchange resins are a variety of different types of exchange materials, which are distinguished into natural or synthetic resin. Furthermore, it can be as well categorized on the bases of functional groups such as cationic exchange resins, anion exchange resins, and chelating exchange resins (Dofner , 1991).

Certain general rules for cation exchange are: (i) the exchanger prefers ions of high charge, (ii) ions of small hydrated volume are preferred, (iii) ions, which interacts strongly with the functional groups of the exchanger are proffered (Leinonen and Lehto,2000; Greenway et al., 1996; Lin et al., 2000; Seco et al.,1999; Kenaway et al., 2000; Verbych et al., 2004; Badawy et al., 2009).

The aim of the present work was to study the removal of Cu^{+2}, Pb^{+2} and Zn^{+2} from industrial wastewater by ion exchange method using Amberlite IR120 resin. In addition, parameters that influence ion exchange, such as contact time, resin dosage, pH and temperature were investigated. The thermodynamic studies and isotherms models and kinetics parameters were also evaluated from the ion exchange measurements.

2. Experimental
2.1. Materials

Analytical grade reagents were used in experimental studies. Copper Sulfate pent hydrated ($CuSO_4.5H_2O$), Lead Nitrate (Pb $(NO_3)_2$) and Zinc Chloride ($ZnCl_2$) from (E. MERK, Denmark) were used for preparing synthetic solutions. pH adjustments were carried out by using 0.1N HCl and 0.1N NaOH.

Amberlite IR120 strong acid cation exchange resin from (Rohm and Hass) was used its physical and chemical properties are given in Table 1.

2.2. Apparatus

GBC 933 plus Atomic Absorption Spectrometer AAS was used to measure concentrations of soluble copper, zinc and lead. Batch experiments were carried out in SI-600R Lab. Companion shaker. wtw series ion lab pH-meter used for pH measurements.

2.3. Equilibrium studies

The batch ion exchange experiments were carried out in the Laboratory of higher studies/ Department of Environmental Engineering/ College of Engineering/University of Baghdad. These experiments were performed in a wide variety of conditions including different pH, various resin dosages and agitation periods. Effects of each factor were determined keeping other variables constant. In the experiments 100 ml of synthetic solutions containing 100 mg/L of one of heavy metal were added into flasks with different amount of resin varying between 0.05 and 0.45g. pH adjustments were made by using 0.1N hydrochloric acid and 0.1N sodium hydroxide. Solutions were shaked at 180 rpm for a predetermined period. At the end of agitation time resins were filtered and metal contents of solution were analyzed by AAS.

3. Results And Discussion
3.1. Effect of pH

Hydrogen ion concentration is an important parameter affecting the ion exchange process. In order to investigate the effect of the pH on removal of heavy metal by Amberlite IR120, 100 ml of 100 mg/l metal solutions were used. Experiments were

performed in the pH range 1-8. Constant resin amount was added to all reaction bottles and solutions were agitated for 2h at 180 rpm speed. Effect of pH on removal efficiency is shown in Figure. 1.

The removal of metals was increased with increasing pH values. At lower values, the metal ion uptake was inhibited in the acidic medium and this can be attributed to the presence of H^+ ions competing with the metal ions for the sorption sites (Rao et al., 2006). The uptake continuously increases with the increase in pH value and the highest uptake was observed at pH equal to 4 for Cu and Pb and pH equal to 6 for Zn.

The removal of lead is greater than copper and zinc at pH of 4; removal efficiency of lead is 99.833, copper is 99.39, and zinc is 98.14 (Pb > Cu >Zn).

3.2. Effect of resin amount

The resin amount is also one of the important parameters to obtain quantitative uptake of metal ion. The dependence of metal sorption on resin input amount was studied by varying the amount of Amberlite IR120 (0.05-0.45g), while the other parameters such as pH 6, initial metal concentration 100 mg/l, agitating time 2h and stirring speed 180 rpm remained constant.

It was apparent that the adsorption percentage of metal ions increased with higher resin dosages. The higher removal efficiency was achieved by using 0.35 g/100 ml resin dosages (Figure 2). This result proved that increasing the amount of adsorbent provides higher removal due to formation of greater adsorption sites.

3.3. Effect of contact time

The effect of contact time on the ion exchange of metal ions by Amberlite IR120 resin was studied by taking 0.35g resin with 100ml of a metal solution in different flasks. The flasks were shaked for different time intervals. Figure 3 shows the effect of contact time on the removal efficiency. The results show that the percentage of metal ion adsorbed increased with increasing time till reaching the equilibrium and it reached the plateau value at 60 minutes.

3.4. Effect of temperature

To investigate the effect of adsorption temperature on the metal adsorption onto the Amberlite IR120, experiments were carried out at three different temperatures (25, 40 and 60°C) with initial concentrations of lead (II), copper (II) and zinc(II) 100mg/L at 60 minutes contact time and 0.35g resin amount and pH 1 and 6 and a constant stirring   speed 180 rpm.   The results show an increase in metal removal is observed by increasing the temperature of the system. The results are given in Figures 4 and 5.

As seen from the figure the removal efficiency of lead increased from 94.974 to 98, zinc from 90 to 94.65, and copper from 82.23 to 91.5 with increasing temperature from 25 to 60°C at pH=1and the removal efficiency of lead increased from 99.476 to 99.95, zinc from 99 to 99.91, and copper from 99.816 to 99.911 with increasing temperature from 25 to 60°C.

3.5. Thermodynamic studies

The amounts of sorption of single metal ions by Amberlite IR120 are measured in temperature 298, 313 and 333 °K. Thermodynamic parameters were calculated for the system by using the equation (Gode and Pehlivan, 2003):

$$\ln K_D = \left(\frac{\Delta S^o}{R} \right) - \left(\frac{\Delta H^o}{RT} \right) \qquad (1)$$

where K_D is the distribution coefficient; ΔH, ΔS, and T the enthalpy, entropy, and temperature in Kelvin, respectively; R is the gas constant. The values of enthalpy and entropy were obtained from the slope and intercept of $\ln K_D$ versus $1/T$ plots (Figures 6 and 7).

Gibbs free energy (ΔG) was calculated using the following equation:

$$\Delta G = \Delta H - T\Delta S \qquad (2)$$

Table 2 summarizes the distribution coefficients from a series of batch experiments at different temperatures. The distribution coefficient values for Zn^{+2}, Pb^{+2} and Cu^{+2} were very high and they increased with temperature and the reaction products are favored at high temperatures. This is due to the endothermic ion exchange reactions of divalent cations.

The values of the thermodynamic parameters for the sorption of metal ions on Amberlite IR120 are given in Table 3. The positive values of enthalpy changes show that the adsorption of metal ions is endothermic. Entropy values were

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Found to be positive due to the exchange of the metal ions with more mobile ions present on Amberlite, which would cause increase in the entropy during the sorption process.

3.6. Adsorption isotherms

Adsorption isotherms are very powerful tools for the analysis of adsorption process. Adsorption isotherms establish the relationship between the equilibrium pressure or concentration and the amount of adsorbate adsorbed by the unit mass of adsorbent at a constant temperature. The Langmuir and Freundlich isotherm models are widely used to investigate the adsorption process.

3.6.1 Langmuir Isotherm Model

Langmuir sorption isotherm models the monolayer coverage of sorption surfaces and assumes that sorption occurs on a structurally homogenous adsorbent and all the sorption sites are energetically identical. The saturated monolayer curve can be represented by the expression (Rao et al., 2006 ; Prasad et al., 2000):

$$Q_e = \frac{X}{m} = \frac{Q_0 b C_e}{1 + b C_e} \quad \text{(non-linear)} \quad (3)$$

A linear form of this equation is:

$$\frac{C_e}{Q_e} = \frac{1}{b Q_0} + \frac{C_e}{Q_0} \quad \text{(linear)} \quad (4)$$

where X is the initial concentration of solute minus the final concentration of solute in solution at equilibrium (mg/l), m is the concentration of adsorbent (mg/l), C_e is the equilibrium concentration of metal in solution (mg/l), Q_e is the amount of metal ion sorbed onto resin (mg/g), b, Q_0 is Langmuir constants representing the equilibrium

3.7. Kinetics of adsorption

Adsorption kinetics provides valuable information about the mechanism of adsorption (Veli and Ozturk, 2005). Rate of adsorption uptake, which is required for selecting optimum operating condition for the full-scale batch process, can be described with adsorption kinetics (Gupta and Sharma, 2003).

Constant for the adsorbate-adsorbent equilibrium and the monolayer capacity. b and Q_0 were determined from the slope, intercept of the Langmuir plot (Figure 8).

3.6.2 Freundlich Isotherm Model

Freundlich equation is derived to model the multilayer sorption and for the sorption on heterogeneous surfaces. The Freundlich isotherm theory says that the ratio of the amount of solute adsorbed onto a given mass of sorbent to the concentration of the solute in the solution is not constant at different concentrations (Rao et al., 2006; Prasad et al., 2000).
The Freundlich equation is:

$$Q_e = K_f C_e^{1/n} \quad \text{(non- linear)} \quad (5)$$

$$\log Q_e = \log K_f + \frac{1}{n} \log C_e \quad \text{(linear)} \quad (6)$$

where Q_e is the amount of solute adsorbed per unit weight of adsorbent (mg/g), C_e is the equilibrium concentration of solute in the bulk solution (mg/l), K_f is a constant indicative of the relative adsorption capacity of the adsorbent (mg/g), $1/n$ is a constant indicative of the intensity of the adsorption.

Both K_f and n are constants, being indicative of the extent of adsorption and the degree of non-linearity between solution and concentration, respectively.

The linear Freundlich plots are obtained by plotting log Q_e versus log C_e from which the adsorption coefficients could be evaluated (Figure 9).
All constants determined from Langmuir and Freundlich isotherms are given in Table 4.

Kinetic studies for zinc, copper and lead were performed by using 100 mg/l concentration, pH was adjusted to 6, resin mass was 0.35g/100 ml. Samples were taken with different time intervals ranging between 5 and 120 minutes.

3.7.1. Pseudo-first order reaction kinetic

Simple linear equation for Pseudo-first order reaction kinetic is (Sharma and Bhattacharyya, 2004):

$$\ln(q_e - q_t) = \ln q_e - k_1 t \quad (7)$$

where k_1 is the rate constant of the first-order adsorption, q_t is the amount of heavy metal adsorbed at time t (mg/g) and q_e is the amount of heavy metal adsorbed at saturation (mg/g). Plot of $\ln (q_e - q_t)$ versus t allows calculation of the rate constant k_1 and q_e (Figure 10).

3.7.2. Pseudo-second order reaction kinetic

Pseudo-second order reaction kinetic can be expressed as (Ho and Mckay, 1998):

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \quad (8)$$

where k_2 is the pseudo-second order rate constant (g/mg h), q_e is the amount adsorbed at equilibrium and q_t is the amount of metal adsorbed at time t.

Calculated rate constants (k_1 and k_2), adsorbed amounts of heavy metals per unit resin mass (q_e) and linear regression correlation coefficients (R^2) for pseudo-first and –second-order reaction kinetics are summarized in Table 5. In pseudo-second-order reaction kinetic, calculated values of q_e are closer to experimental values for zinc, copper and lead. Furthermore as seen from Table 5, correlation

Similar to pseudo-first order reaction kinetic, q_e and k_2 can be determined from the slope and intercepts of plot t/q_t versus t (Figure 11).

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coefficients are higher for second order kinetic studies.

4. Conclusion

In this paper optimal removal conditions were determined with batch experiments. Ion exchange processes was pH-dependent and optimal removal efficiencies for zinc at pH 6, copper and lead at pH 4. Adsorption of the three metal ions reaches equilibrium within 60 minutes and 0.35g/100 ml of resin.

The thermodynamic parameters of ion exchange process were calculated. Ion exchange equilibrium at temperatures 298 , 313 and 333°K of Zn, Cu, and Pb are found to be endothermic processes.

Experimental results were evaluated with Langmuir and Freundlich; the results show Freundlich isotherm fit the ion exchange equilibrium data better than the Langmuir.

Pseudo-second-order reaction kinetic has provided a realistic description of removal of Zn, Cu, and Pb with closer experimental and calculated values of q_e. Also correlation coefficients are higher in pseudo-second-order kinetics.

Experimental and theoretical results of this study demonstrate that the Amberlite IR120 cation exchange resin is suitable for adsorption of zinc, copper, and lead from aqueous solutions.

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Table 1: Characteristics of Amberlite IR120.

Matrix	Styrene
Functional group	Sulfunic acid
Particle size (mm)	0.3-1.2
Maximum temperature (°C)	120
pH range	0-14
Total capacity (equiv/l)	1.8

Table 2: Distribution coefficients of heavy metal at different temperatures.

pH=1				
Metal	k_d			R^2
	298°K	*313°K*	*333°K*	
Zn	2.5714	3.7959	5.0547	0.9809
Pb	5.3990	11.1429	14.0000	0.8869
Cu	1.3221	2.3117	3.0756	0.9456
pH=6				
Metal	k_d			R^2
	298°K	*313°K*	*333°K*	
Zn	66.7834	158.4444	317.1746	0.9871
Pb	54.2399	123.9379	571.1429	0.9858
Cu	23.8456	50.7347	320.7416	0.9656

Table 3: Thermodynamic parameters for the adsorption of metal ions on Amberlite IR 120.

pH=1					
Metal	ΔH (kJ/mol)	ΔS (J/mol K)	ΔG (kJ/mol)		
			298°K	*313°K*	*333°K*
Cu	19.6609	68.8216	-20.4892	-21.5215	-22.8979
Zn	15.8191	61.1819	-18.2164	-19.1341	-20.3578
Pb	22.0604	88.9182	-26.4756	-27.8093	-29.5877
pH=6					
Metal	ΔH (kJ/mol)	ΔS (J/mol K)	ΔG (kJ/mol)		
			298°K	*313°K*	*333°K*
Cu	61.8595	232.6598	-69.2708	-72.7607	-77.4139
Zn	36.5134	157.9244	-47.0249	-49.3938	-52.5523
Pb	55.8360	219.8222	-65.4512	-68.7485	-73.1449

Table 4: Isotherm parameters calculated for zinc, copper and lead removal by Amberlite IR120.

Metals	Langmuir isotherm			Freundlich isotherm		
	b	Q_e	R^2	n	K_f	R^2
Zn	0.092486	312.5000	0.6156	1.517451	29.76457	0.9648
Pb	0.415493	169.4915	0.9776	2.504383	44.09608	0.9847
Cu	0.095238	178.5714	0.7994	2.159827	24.37250	0.9463

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Table 5: Comparison of adsorption rate constants, experimental and calculated q_e values for the pseudo-first- and –second-order reaction kinetics of removal of zinc, copper and lead by Amberlite IR120.

Metals	$q_{e\ experimental}$ (mg/g)	Pseudo-first-order			Pseudo-second-order		
		K_1 (1/min)	$q_{e\ calculated}$ (mg/g)	R^2	K_2 (g/mg min)	$q_{e\ calculated}$	R^2
Zn	28.4286	0.0785	13.4180	0.9374	0.0222	28.8184	0.9999
Cu	28.3971	0.0760	17.9179	0.9607	0.0114	29.2398	0.9998
Pb	28.5237	0.0991	16.3988	0.9565	0.0173	29.1545	0.9997
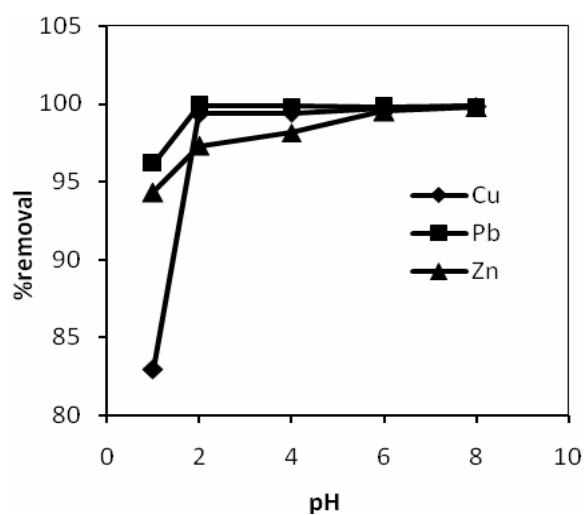
Fig. 1: Effect of pH on removal of zinc, lead, and copper by Amberlite IR120
(initial metal conc. 100 mg/L, resin dosage 0.35 g/100 mL, agitation period 2 h).
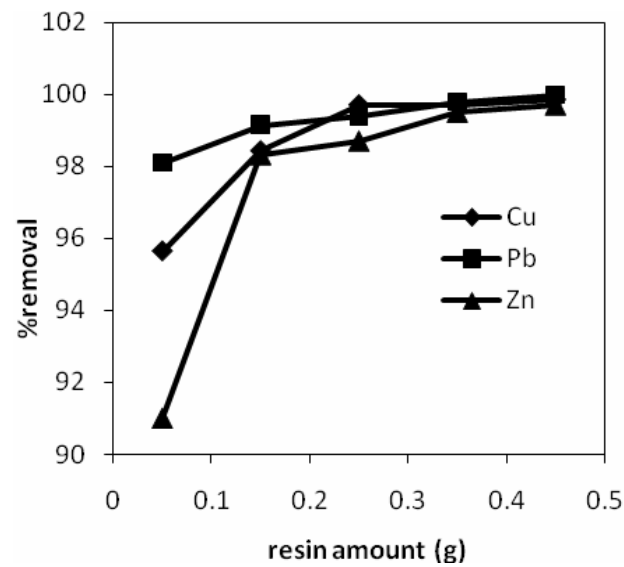
Fig. 2: Effect of resin amount on removal of zinc, lead, and copper by Amberlite
IR120 (initial metal conc. 100 mg/L, pH 6, agitation period 2 h)
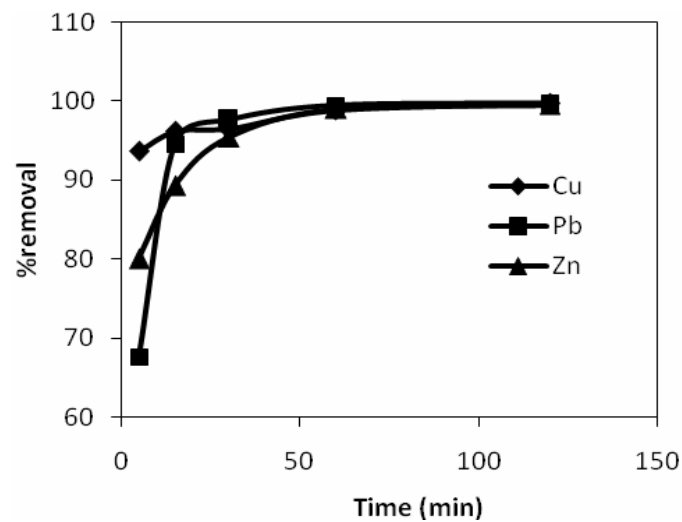
Fig. 3: Effect of contact time on removal of zinc, lead, and copper by Amberlite
IR120 (initial metal conc. 100 mg/L, pH 6, resin amount 0.35 g/ 100 ml).

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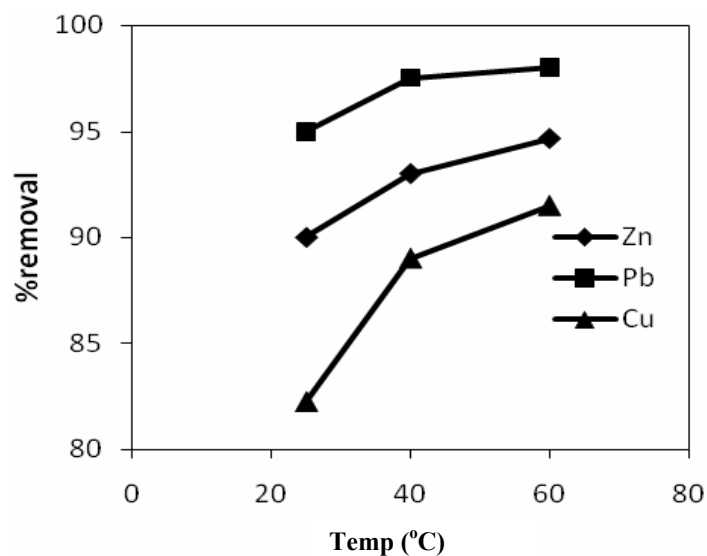
Fig. 4: Effect of temperature on removal of zinc, lead, and copper by Amberlite IR120
(initial metal conc. 100 mg/L, pH 1, resin amount 0.35 g/ 100 mL, contact time 60 min).
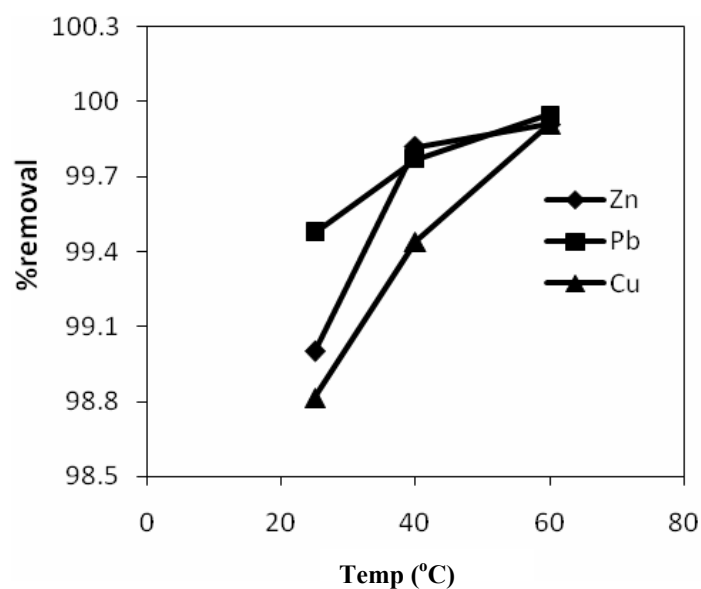
Fig. 5: Effect of temperature on removal of zinc, lead, and copper by Amberlite IR120 (initial
metal conc. 100 mg/L, pH 6, resin amount 0.35 g/ 100 mL, contact time 60 min).
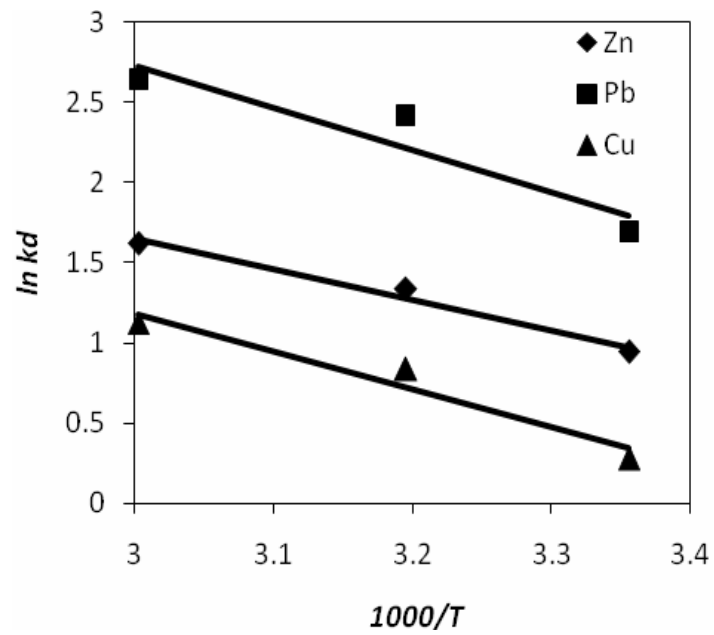
Fig. 6: The distribution coefficient versus 1/temperature at pH 1.
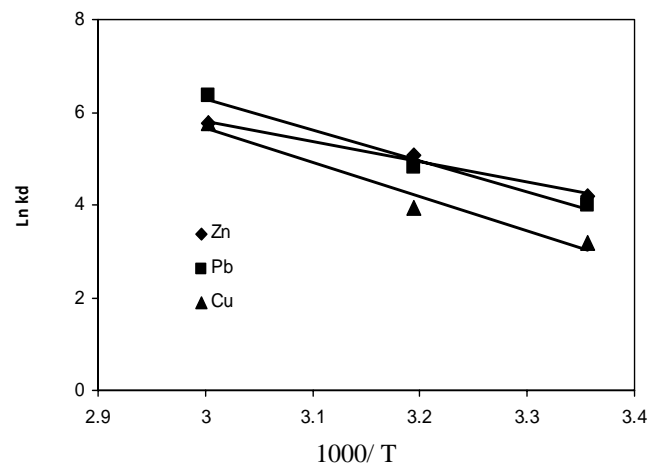
Fig. 7: The distribution coefficient versus 1/temperature at pH 6.
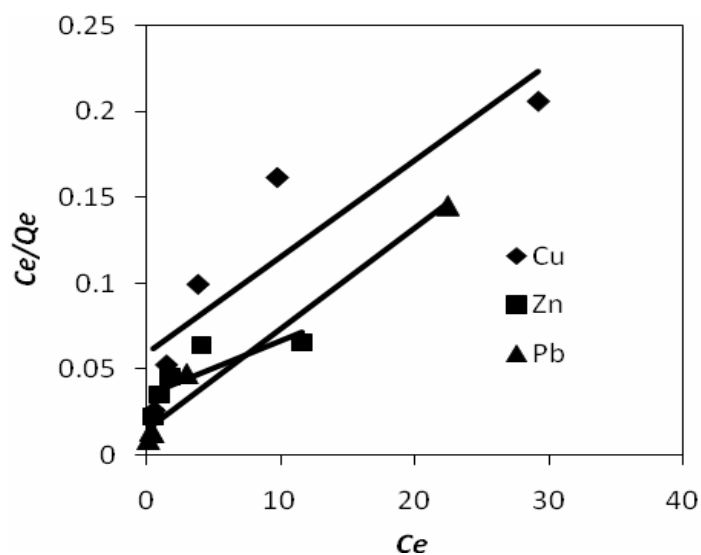
Fig. 8: Langmuir adsorption isotherm for removal of zinc, copper and lead
by Amberlite IR120.
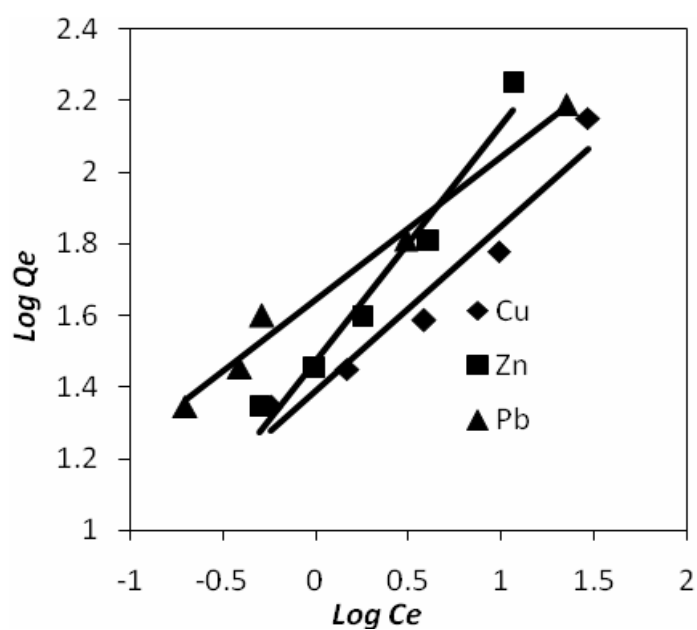
Fig. 9: Freundlich adsorption isotherm for removal of zinc, copper and lead
by Amberlite IR120.
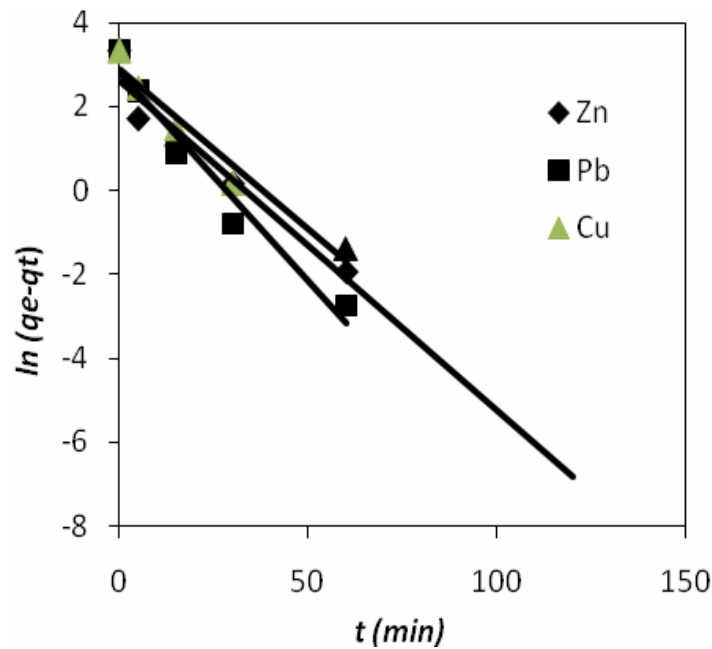
Fig.10: Pseudo-first-order reaction kinetics for the adsorption of zinc, copper and lead.
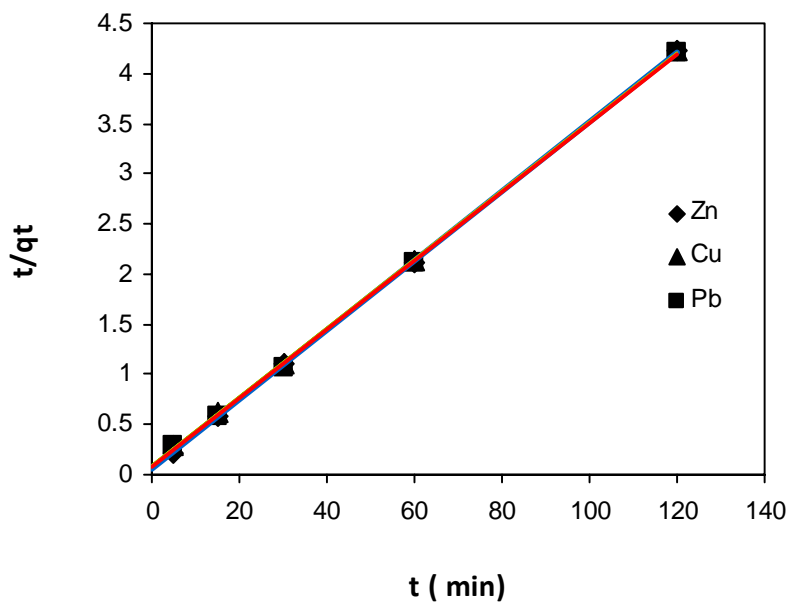
Fig. 11: Pseudo-second-order reaction kinetics for the adsorption of zinc, copper and lead.

Simulation of Heat Storage and Heat Regeneration in Phase Change Material

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Abstract

The present study explores numerically the energy storage and energy regeneration during Melting and Solidification processes in Phase Change Materials (PCM) used in Latent Heat Thermal Energy Storage (LHTES) systems. Transient two-dimensional (2-D) conduction heat transfer equations with phase change have been solved utilizing the Explicit Finite Difference Method (FDM) and Grid Generation technique. A Fortran computer program was built to solve the problem. The study included four different Paraffin's. The effects of container geometrical shape, which included cylindrical and square sections of the same volume and heat transfer area, the container volume or mass of PCM, variation of mass flow rate of heat transfer fluid (HTF), and temperatures difference between PCM and HTF were all investigated.
Results showed that the PCMs in a cylindrical container melt and solidify quicker than the square container. The increase in mass flow rate and/or temperature difference decreases the time required for complete phase change. Paraffin's solidify quicker than they melt and store more energy than they release.

Keywords: Phase change material; Latent heat thermal energy storage; Melting; Solidification; Energy storage; Energy regeneration; Grid generation

الخلاصة:

تتحرى الدراسة الحالية عددياً الطاقة المخزونة والطاقة المتحررة أثناء عمليتي الذوبان والانجماد في مادة متغيرة الطور تستخدم في منظومات خزن الحرارة الكامنة. حلت معادلة انتقال الحرارة الانتقالية باتجاهين باستخدام طريقة الفروق المحددة الصريحة وبتقنية التوليد الشبكي. تم بناء برنامج حاسوبي بلغة فورتران لحل المسألة. تتضمن الدراسة أربعة برافينات متغيرة الطور، تأثير الشكل الهندسي لوحدة الخزن الذي تضمن المقطعين الدائري والمربع للحجم نفسه و مساحة انتقال الحرارة نفسها، حجم الخزان أو كتلة المادة المتغيرة الطور، تغيير نسبة التدفق لسائل نقل الحرارة، وفرق درجات الحرارة بين المادة متغيرة الطور وسائل نقل الحرارة.
بينت النتائج إن المادة متغيرة الطور في وحدات الخزن الحراري الاسطوانية تذوب وتتجمد أسرع مما في وحدات الخزن الحراري المربعة. زيادة نسبة التدفق و فرق درجات الحرارة يقلل الزمن اللازم لتغير الطور التام. البرافينات تتجمد أسرع مما تذوب وتخزن طاقة أكثر مما تحرر.

1. Introduction:

Thermal Energy Storage (TES) is essential to overcome the mismatches between the supply and consumption of energy or primary energy source variation, such as periodic variations of solar energy.

Phase Change Material (PCM) used for Latent Heat Storage (LHS) has received considerable attention attributed to its high storage density and isothermal nature of heat storage and release. There are many type of PCMs; organic, inorganic and their mixture that melt and solidify at a wide range of temperatures. This makes them attractive in a number of applications, such as; space and water heating, waste heat utilization, cooling and air-conditioning, and thermal control applications (Regin et al. 2008).

Paraffins have been used extensively as a latent heat energy material due to their advantages of a sufficiently high latent heat capacity, small volume changes during phase change, no sub-cooling effects, self-nucleating behavior, chemically stable, long freeze–melt cycle, nonpoisonous, noncorrosive, as well being available at low cost (Sharma et al. 2009).

Phase change is a transient, non-linear heat transfer mechanism with a moving solid-liquid interface, generally referred to as the "Moving Boundary " or "Stefan's" Problem(Lane 1983). The most common methods used for solving phase change problems are the enthalpy method and the effective heat capacity method (Lamberg et al. 2004). Phase change problems are usually solved with finite difference or finite element methods in accordance with the numerical approach. Previous studies can be divided into two main group; material research and heat exchanger development (Regin et al. 2008). PCMs with organic nature, inorganic and their mixture for heating and cooling applications has been investigated by many researchers. These applications can be divided into two main groups: thermal

protection or inertia, and storage. PCMs store one hundred times more heat per unit mass than sensible storage materials such as water, or rock. Sarı and Karaipekli 2008 illustrated the basic types of PCM employed in LHTES systems and the main characteristics required for them. Hasan 1994 developed a simple tube-in-tube heat exchanger for TES with stearic acid as a PCM. He found that the melting front moves in the radial direction inward as well as in the axial direction from the top toward the bottom of the PCM tube. Phase transition was faster in a horizontal position rather than a vertical one. Esen et al. 1998 Considered two different shell and tube configurations where the PCM is packed in the tube and the HTF flows parallel to it in the shell and vice versa. It was concluded that the latent heat storage tank where the PCM is packed in the shell while the HTF flows through the tube stores much more solar energy in a given time as compared to the other configuration. Yimer 1996 developed a numerical model to determine the transient temperature distribution, solid/liquid interface location, and energy-storage capacity of a semi-transparent phase-change medium bounded between two concentric cylinders. Internal energy transfer occurs simultaneously by conduction and thermal radiation. Gong and Mujumdar 1998 have simulated the melting of a pure PCM in a rectangular container heated from below using the FEM. They obtained several complex and time-dependant flow patterns. Zivkovic and Fujii 2001 concluded that the rectangular container requires half of the melting time as for the cylindrical container of the same volume, using a simple computational model based on an enthalpy formulation. They also concluded that conduction within the

PCM in the direction of HTF flow, thermal resistance of the container's wall, and the effects of natural convection within the melt can be ignored for the conditions

investigated. Trp et al. 2006 studied the influence of the HTF inlet velocity and HTF inlet temperature as well as the influence of the tube length and outer tube radius on the total energy stored and recovered in shell and tubes LHTES system. Vyshak and Jilani 2007 made a comparative study of the total melting time of PCM packed in containers having three different geometric configurations, viz. rectangular, cylindrical and a cylindrical shell of the same volume and surface area of heat transfer. They employed a slightly modified enthalpy method, which enabled decoupling of the temperature and liquid fraction fields.

Mathematical Modeling:
2.1 Problem Description:

The present study involved two concentric tubes for the LHTES systems. The PCM fills the annular space between the two tubes, the HTF flows through the inner tube, and the outer tube is completely insulated.

During the charging process the PCM acts as a heat sink which receives energy from HTF whose temperature is higher than the PCM's melting temperature. The PCM melts and energy is stored as latent heat. During the discharging process, the PCM acts as a heat source to the HTF whose temperature is lower than the PCM's solidification temperature. The PCM solidifies and heat is released to the HTF.

Two geometrical configurations of the PCM's container were involved. The first was of a circular cross section and the second was of a square cross section, as shown in **Fig.1**. Three container volumes, i.e. mass of PCM were considered. The inner tube diameter (D_i) is 0.5 inch for all studied cases. For the

cylindrical configuration, the outer tube diameters (D_o) were 1, 1.5, and 2 inches that equal to 25.4, 38.1, and 50.8 mm respectively. The square configuration have the same volume so the side width (2w) were 22.51, 33.76, and 45.02 mm

respectively. Due to symmetry of the system, the computational domain is composed of only one quarter of the cross section.

Four types of paraffins having different melting points, of 28, 48, 64, and 84°C, suitable for solar applications, were employed as PCM, and water as HTF.

The study included the effect of different mass flow rates of the HTF at 1 and 3 l/min, and the effect of temperature difference between the PCM and the HTF at 15 and 25 ^{o}C.

2.2 Assumptions:

The following assumptions were made to simplify the phase change problem:
1. The PCM in each phase is homogeneous and isotropic.
2. The thermo-physical properties of the PCM are independent of temperature, but they are different form phase to phase.
3. The effect of natural convection in the liquid phase of PCM is not taken into account.
4. No internal heat generation , and all radiation effects are neglected.
5. The tube wall is very thin so that its thermal resistance can be neglected.

2.3 Governing Equations:

The energy equation for transient two dimensional (2-D) conduction heat transfer with phase change can be written as;

$$\rho_b c_b \frac{\partial T}{\partial t} = k_b \left[\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} \right]$$

The subscripts b denote the material properties for each phase. The physical fact that the phase change takes place in a temperature interval (from T_1 to T_2) can be used. Thus;

$b = s$ (solid phase properties) when $T < T_1$

$b = m$ (mushy zone properties) when $T_1 \leq T \leq T_2$

b = l   (liquid phase properties) when $T > T_2$

The density and the thermal conductivity of the mushy zone can be estimated as an arithmetic average;

$$\rho_m = \frac{1}{2}(\rho_s + \rho_l), \quad k_m = \frac{1}{2}(k_s + k_l)$$

While the specific heat can be found from the effective heat capacity method (Lamberg et al.2004);

$$c_m = c_{eff} = \frac{LH}{T_2 - T_1} + \frac{1}{2}(c_{ps} + c_{pl}) \qquad (4)$$

3. Numerical Solution:
3.1 Body-Fitted Coordinate System:

The nature of numerical calculations of the zone requires a proper treatment of the boundary conditions. The system which is made to generate a grid, might bring about a slow numeric convergence. This has encouraged the search for other methods to generate grids. One method includes the generation of curvilinear coordinate systems with coordinate lines coincident with all boundaries of the physical domain. This is called a body fitted coordinate (BFC) system. Regardless of the shape of the body in the physical plane, all the numerical computations are achieved in the form of a rectangular grid in the computational domain, as shown in **Fig.**

3.2 Grid Generation:

The method for generation of a curvilinear body fitted coordinate system is based on solution of a set of elliptic partial differential equations. The most common elliptic partial differential equations used for grid generation in two-dimensions is the Laplace equation in the form, (Hoffmann 1998);

$$\frac{\partial^2 \zeta}{\partial x^2} + \frac{\partial^2 \zeta}{\partial y^2} = 0 \qquad (5)$$

$$\frac{\partial^2 \eta}{\partial x^2} + \frac{\partial^2 \eta}{\partial y^2} = 0 \qquad (6)$$

However, computations must take place in a rectangular domain with uniform grid spacing. To transform the elliptic PDEs, the dependent and independent variables are interchanged and these equations become;

$$\alpha \frac{\partial^2 x}{\partial \zeta^2} - 2\beta \frac{\partial^2 x}{\partial \zeta \partial \eta} + \gamma \frac{\partial^2 x}{\partial \eta^2} = 0 \qquad (7)$$

$$\alpha \frac{\partial^2 y}{\partial \zeta^2} - 2\beta \frac{\partial^2 y}{\partial \zeta \partial \eta} + \gamma \frac{\partial^2 y}{\partial \eta^2} = 0 \qquad (8)$$

The system of elliptic Equations (7) and (8) will be solved by the Successive Over-Relaxation (S. O. R.) method in the computational domain (ζ, η) in order to provide the grid point locations in the physical space (x, y) as follows, (Petrovic and Stupar 1996);

$$x_{(i, j)} = (1-RF)\, x^o_{(i, j)} + [(\alpha_{(i, j)}/\Delta\zeta^2)(x_{(i+1, j)} + x_{(i-1, j)}) - (\beta_{(i, j)}/2\Delta\zeta.\Delta\eta)\,(x_{(i+1, j+1)} - x_{(i+1, j-1)} - x_{(i-1, j+1)} + x_{(i-1, j-1)}) + (\gamma_{(i, j)}/\Delta\zeta^2)(x_{(i, j+1)} - x_{(i, j-1)})]\,RF \quad (9)$$

$$y_{(i, j)} = (1-RF)\, y^o_{(i, j)} + [(\alpha_{(i, j)}/\Delta\zeta^2)(y_{(i+1, j)} + y_{(i-1, j)}) - (\beta_{(i, j)}/2\Delta\zeta.\Delta\eta)\,(y_{(i+1, j+1)} - y_{(i+1, j-1)} - y_{(i-1, j+1)} + y_{(i-1, j-1)}) + (\gamma_{(i, j)}/\Delta\zeta^2)(y_{(i, j+1)} - y_{(i, j-1)})]\,RF \quad (10)$$

3.3 Explicit Finite Difference Method:

The explicit finite difference method includes the calculation of the temperature for a next time $(t + \Delta t)$ in terms of the temperature at the previous time (t) for the node (i, j) and to its neighboring nodes. In each node in the grid, the temperature will be known at time $(t = 0)$ from the initial condition of the problem. So, the temperature for each node will be obtained at the new time step by marching forward in time. It is possible, by the use of time steps Δt to arrive at the steady state and obtain the distribution of temperature, (Anderson 1995).

the governing equation (1), may be transformed from Cartesian coordinates into general coordinates as follows;

$$\frac{\partial T}{\partial t} = \frac{k_b}{\rho_b c_{pb}}\left[\left(\lambda\frac{\partial T}{\partial \zeta} + \sigma\frac{\partial T}{\partial \eta} + \alpha\frac{\partial^2 T}{\partial \zeta^2} - 2\beta\cdot\frac{\partial^2 T}{\partial \zeta\,\partial \eta} + \gamma\frac{\partial^2 T}{\partial \eta^2}\right)/J^2\right] \tag{11}$$

Transformation of the time derivative of temperature, using forward differences, at node (i, j), through the periodic from (t) to time $(t + \Delta t)$ takes the following forms;

$$\frac{\partial T}{\partial t} = \frac{T^{n+1}_{(i,j)} - T^{n}_{(i,j)}}{\Delta t} \tag{12}$$

Where:

Represents the temperature at $(t + at)$.

Represents the temperature at (t).

$$\frac{\partial T}{\partial \zeta} = \frac{T_{(i+1,j)} - T_{(i-1,j)}}{2\Delta \zeta} \tag{13}$$

And, the central differences will be used to transform the diffusion terms, as follows;

$$\frac{\partial^2 T}{\partial \zeta^2} = \frac{T_{(i+1,j)} - 2T_{(i,j)} + T_{(i-1,j)}}{\Delta \zeta^2} \tag{14}$$

$$\frac{\partial T}{\partial \eta} = \frac{T_{(i,j+1)} - T_{(i,j-1)}}{2\Delta \eta} \tag{15}$$

$$\frac{\partial^2 T}{\partial \eta^2} = \frac{T_{(i,j+1)} - 2T_{(i,j)} + T_{(i,j-1)}}{\Delta \eta^2} \tag{16}$$

$$\frac{\partial^2 T}{\partial \zeta\,\partial \eta} = \frac{T_{(i+1,j+1)} - T_{(i+1,j-1)} - T_{(i-1,j+1)} + T_{(i-1,j-1)}}{4\Delta \zeta\cdot\Delta \eta} \tag{17}$$

Now, the energy equation (11) will be transformed into a system of linear equations, as follows;

$$T^{n+1}_{(i,j)} = T^{n}_{(i,j)} + \Delta t\left[\alpha_b\left(\left(\lambda_{(i,j)}\frac{T^{n}_{(i+1,j)} - T^{n}_{(i-1,j)}}{2\Delta \zeta} + \sigma_{(i,j)}\frac{T^{n}_{(i,j+1)} - T^{n}_{(i,j-1)}}{2\Delta \eta}\right.\right.\right.$$
$$+ \alpha_{(i,j)}\frac{T^{n}_{(i+1,j)} - 2T^{n}_{(i,j)} + T^{n}_{(i-1,j)}}{\Delta \zeta^2}$$
$$- 2\beta_{(i,j)}\frac{T^{n}_{(i+1,j+1)} - T^{n}_{(i+1,j-1)} - T^{n}_{(i-1,j+1)} + T^{n}_{(i-1,j-1)}}{4\Delta \zeta\cdot\Delta \eta}$$
$$\left.\left.\left.+ \gamma_{(i,j)}\frac{T^{n}_{(i,j+1)} - 2T^{n}_{(i,j)} + T^{n}_{(i,j-1)}}{\Delta \eta^2}\right)/J^2\right)\right] \tag{18}$$

3.4 Solution Procedure:

A computer program in FORTRAN 90 language was built to solve the phase change problem. At first, the constants and variables were defined which included the thermo-physical properties of the PCM, the initial and boundary conditions, the dimensions of the geometry, number of nodes and the maximum time step (Δt_{max}) that ensures the stability of the solution. The computer program consists of two main parts, the first part is the grid generation. This part starts from the information of the geometry and then the 2D grids consist of many subroutines for transforming the physical plane (x, y) to the

computational plane (ζ, η) in a Body-Fitted coordinate system. The second part is the solution of the governing equations. This part starts from initial specifications of all fields of the dependent variables and the transformation parameters that were obtained from the grid generation. The final set of algebraic discretized equations is solved by the explicit finite difference method.

4. Results And Discussion:

4.1 Temperature Profile:

The temperature profiles are presented for a typical peripheral point at the container surface. This represents the last point affected by the heat source or sink and indicates complete melting or solidification time.

In general, the temperature profile can be divided into three main typical stages for melting and solidification as shown in **Fig. 3**. In the first stage; for melting, the temperature of the PCM increases linearly from its initial value till the lower limits of the melting range. While in solidification, the temperature of the PCM decreases linearly from its initial value till the upper limits of the solidification range.

In the second stage; the temperature of the PCM remains at a nearly constant value about the melting or solidification temperature. The temperature range varies from 1 to 3 °C, which represent the lower and the upper limits of melting or solidification temperature range. The end of this stage means that the material is totally melted or solidified, i.e. the phase is completely changed.

In the third and last stage; the temperature of the PCM changes linearly again but at a lower rate due to a small temperature difference between the PCM and HTF than the first stage. In melting, the temperature rises to a temperature that equals the HTF temperature and then

remain constant. While in solidification, the temperature of the PCM decreases to a final temperature that equals the HTF temperature and then remains constant.

The temperature history for different paraffins have the same profile in all studied cases. **Fig. 4** shows the temperature history during melting process and **Fig. 5** shows the temperature history during solidification process for paraffin 48, which is chosen as a typical case. Paraffin 48 starts melting at 47 °C and totally melts at 49 °C, while it starts solidifying at 49 °C and totally solidifies at 47 °C.
These two figures show the effect of geometrical shape on the temperature profile. It is clear from the results that the PCM stored in the circular cross section container melts and solidifies quicker than that stored in square cross section container, and the PCM solidified quicker than it melts.

The results revealed that the greatest effect is related to the temperature difference as shown in **Fig. 6**. The temperature difference is the dominant factor on the heat transfer rates. Therefore, the effect of the mass flow rate of the HTF become insignificant at the higher temperature difference as shown in **Fig. 7**.

The effect of mass flow rate is translated as an effect of the convective heat transfer coefficient. **Fig. 8** and **Fig. 9** show the effect of the different convective heat transfer coefficients h_f on the temperature profile at 25 °C and at 15 °C temperature difference respectively. As mentioned before, one can note that the effect of the convective heat transfer coefficient becomes significant at the lower temperature difference value.

4.2 Temperature Distribution:
Fig.10 shows the temperature distribution during a melting process, and **Fig. 11** shows the temperature distribution during a

Solidification process at different time intervals. In all studied cases the circular cross section container melts and solidifies quicker than the square cross section container. In early time steps, the temperature distribution appears the same for both container shapes. Later, the square cross section container shows a higher resistance for melting or solidification at its corner due to the longer distance from the heat source or heat sink. Therefore, part of the PCM stays solid at the corner of the square cross section container during melting, while the whole PCM is melted in the circular cross section container. The same thing occurs in solidification where part of the PCM stays liquid at the corner of the square cross section container, while the PCM in the circular cross section container is totally solidified.

4.3 Time of melting and solidification:

Melting or Solidification time is defined as the time required to completely change the material from one phase to the other. Also, it is defined as the time required for charging or discharging energy. It is a very important factor in design and development of LHTES systems.

The effect of various factors on melting and solidification time are discussed in the following;

a. Effect of the Geometrical Design:

The results show that the PCM in a cylindrical container melts and solidifies quicker than in the rectangular container for the same volume (i.e. the same mass of the PCM) and same inner tube diameter (i.e. the same heat transfer area) for all studied cases as shown in **Fig. 4**, **5**, **10**, and **11**.

b. Effect of Container Volume:

As expected, the increase in container volume leads to increases in melting and solidification time as a result of the larger mass of the PCM and higher energy stored or regenerated. From **Fig. 12**, one can note that increasing of the cylindrical container diameter from 1 inch (i.e. aspect ratio 2) to

2 inches (i.e. aspect ratio 4) leads to increasing melting or solidification time from 5 to 10 times.

c. Effect of the PCM type:

Paraffin 48 has a good latent heat but low thermal conductivity. Therefore, it needs the longest time for melting and solidification. Paraffin 84 has the least latent heat but the highest thermal conductivity. Therefore, it melts and solidifies quicker than other three PCMs, as shown in **Fig. 12**.

d. Effect of initial and boundary conditions:

Fig. 13 shows that decreasing the temperature difference from 45°C to 35°C increases the melting time by 40 minutes. Whilst decreasing the temperature difference from 25°C to 15°C increases the melting time by 150 minutes. It is concluded that the reduction of the temperature difference has a more pronounced effect on melting and solidification time at lower values of ΔT.

Increasing the mass flow rate of the HTF leads to shorter melting and solidification times. **Fig. 14** shows this effect. Increasing mass flow rate from 1 to 2 l/min decreases the melting time by only 5 minutes. Therefore, the effect of the mass flow rate is less pronounced than the effect of the temperature difference. The effect of mass flow rate can be translated into the effect of convective heat transfer coefficient. This effect is much more evident at the lower value of temperature difference as shown in **Fig. 15**.

In all cases, the results show that the solidification time is shorter than the melting time. This means that the PCM needs more time to absorb energy than the time needed to release energy. The difference between melting and solidification times is related to the nature of the PCM and its thermo-physical properties. During solidification, liquid PCM freezes on the heat transfer surfaces and an immobile layer of solid material continuously grows as it gives up heat of

fusion. This solid layer, generally, has a higher thermal conductivity and heat transfer is improved, which in turn decreases the energy release time.

4.4 Energy Storages and Energy Regeneration:

The mass flow rate of the HTF, in the range investigated, has no significant effect on energy storage or regeneration. Its only effect is on the time of charging or discharging energy. Increasing the mass flow rate accelerates the period of melting and solidification. Increasing the temperature difference between HTF and PCM decreases the energy receival/retrieval time, as well as increasing the share of sensible heat of the total energy stored or regenerated.

The most important factor on the energy storage and energy regeneration is the thermo-physical properties of the PCM such as; latent heat, heat capacity, and density.

The present results show that the heat storage is higher than the heat generation as shown in **Fig. 16** and **Fig. 17**. The difference between energy stored and energy regenerated is related to the nature of the PCM and its thermo-physical properties. PCM receives energy initially as a solid phase during melting and stores energy in the liquid phase. The inverse occurs when energy is extracted from the liquid phase during solidification and some of energy may be reserved in the solid material.

5. Conclusions:

1. Temperature history have the same profile in all studied cases.
2. Temperature difference between the PCM and the HTF is the dominant factor on the heat transfer rates.
3. Mass flow rate of the HTF becomes insignificant at the higher temperature difference.

4. Cylindrical container melts/solidifies quicker than the square container.
5. Melting time is longer than solidification time.
6. Heat storage is higher than heat regeneration.

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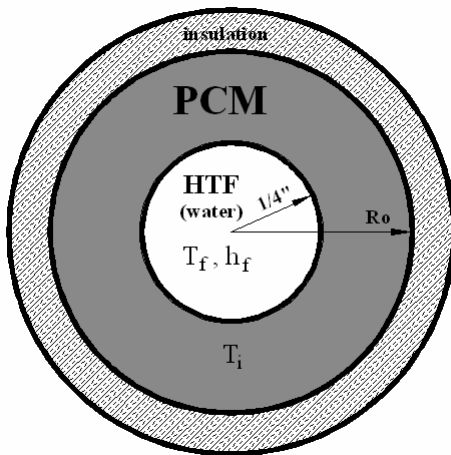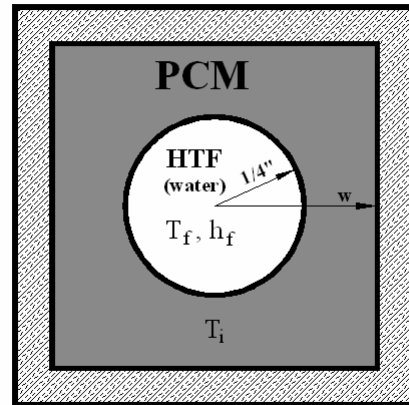
(a) cylindrical container   (b) Rectangular container

Figure 1 Two geometrical designs considered in the present study, same volume, same inner tube diameter.
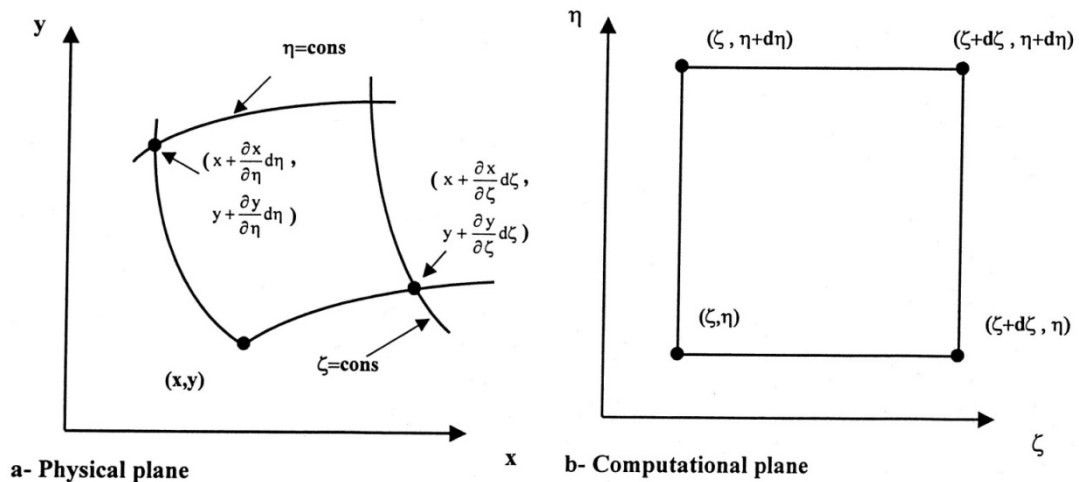
Figure 2 Element transformation from the physical to the computational plane.
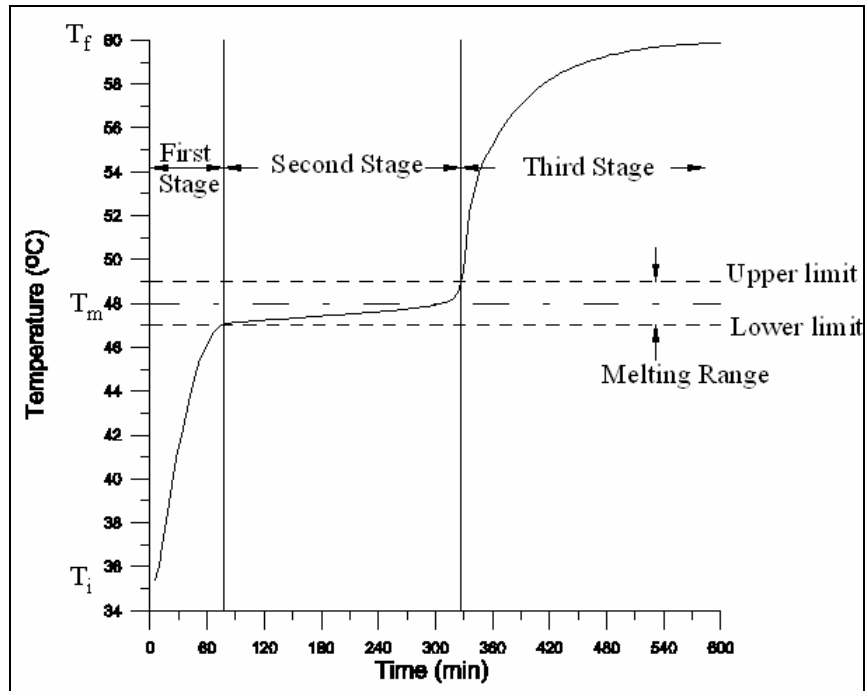
(a) Melting process
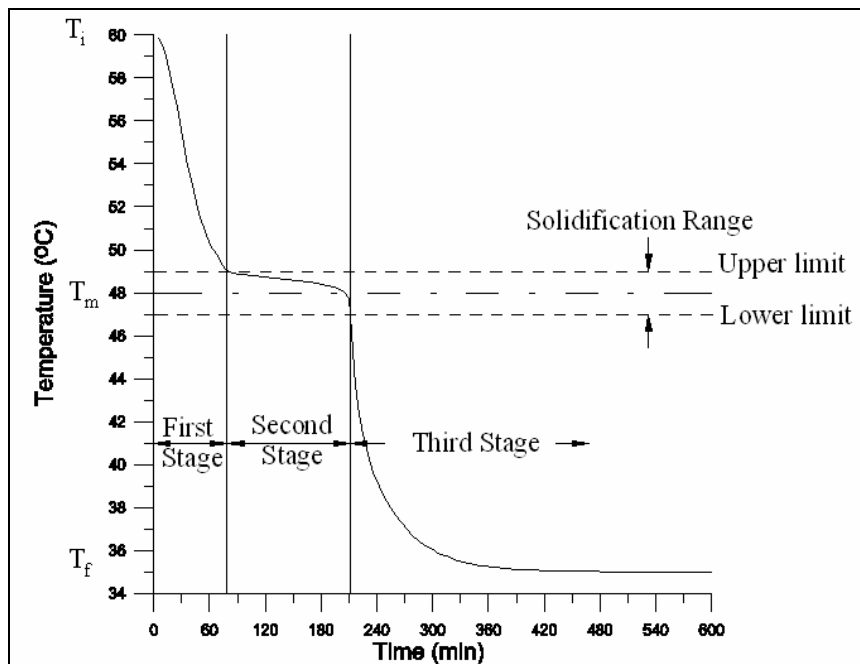
(b) Solidification process

Figure 3 Typical Temperature-Time profile for selected case. PCM2/Vol.3; $\Delta T=25^{o}C$, m_f=3 l/min
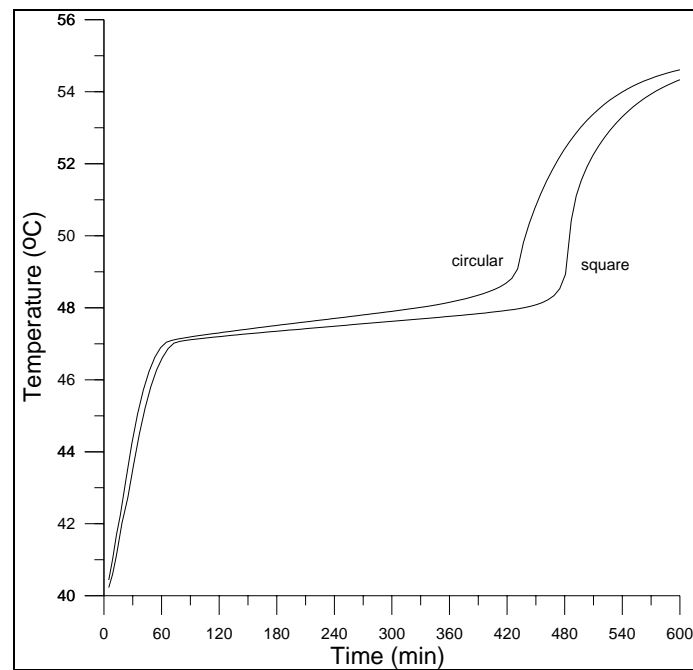
Figure 4 Temperature History during Melting Process for two geometrical designs (circular and square container). PCM2/Vol.3; ΔT = 15 ᵒC, m_f = 3 l/min
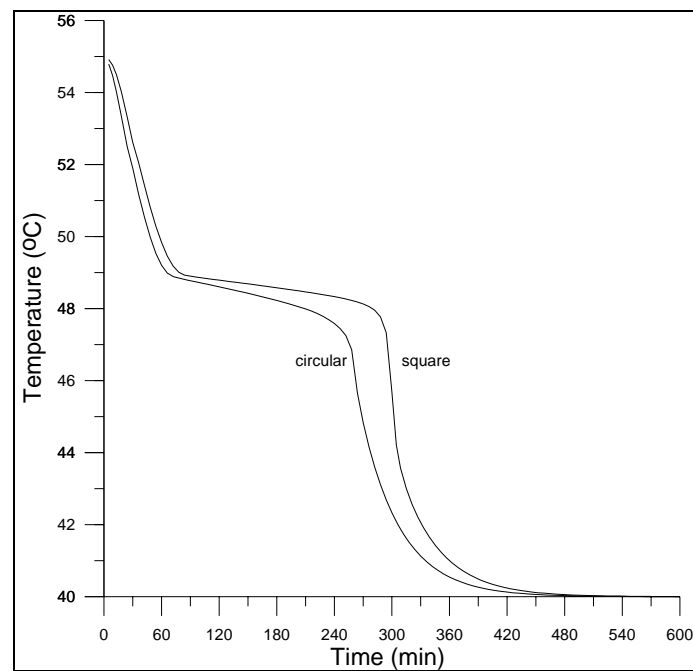
Figure 5 Temperature History during solidification Process for two geometrical designs (circular and square container). PCM2/Vol.3; ΔT = 15 ᵒC, m_f = 3 l/min.
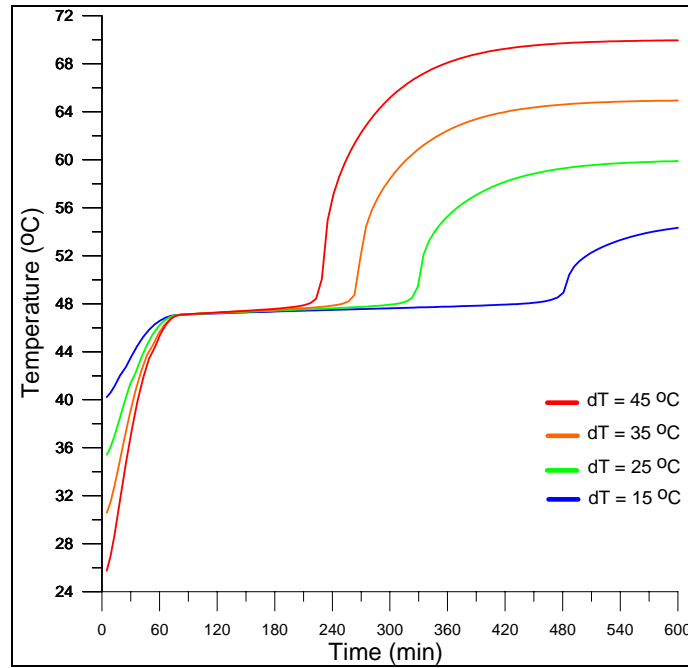
Figure 6 Temperature History during Melting Process of Paraffin (48 ^{o}C) at various Temperature difference (dT =T_f - T_i); 15, 25, 35 and 45 (^{o}C) ; m_f = 3 l/min
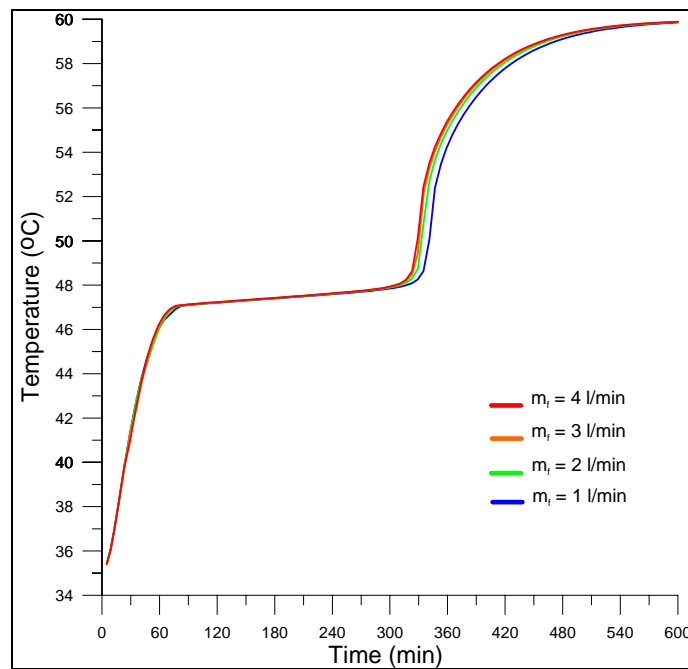
Figure 7 Temperature History during Melting Process of Paraffin (48 ^{o}C) at different mass flow rate; 1, 2, 3 and 4 (l/min), ΔT = 25 ^{o}C
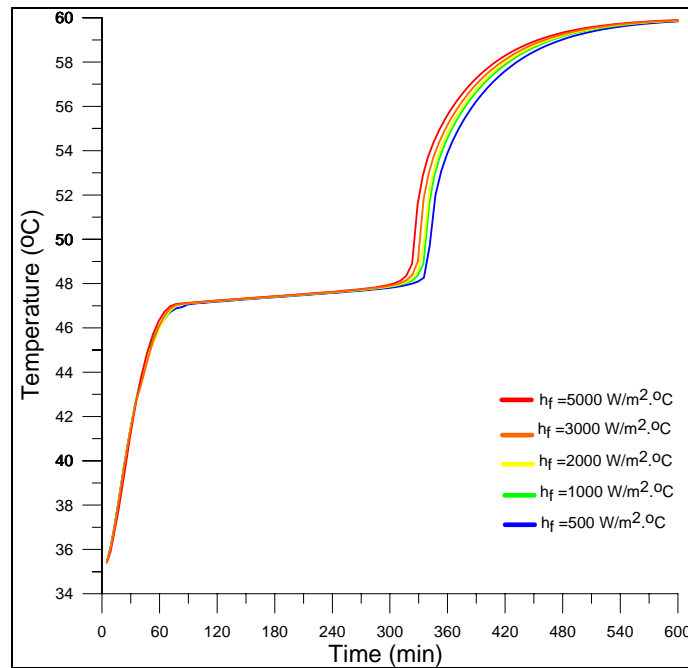
Figure 8 Temperature History during Melting Process of Paraffin (48 ^{o}C) at different Convection Heat Transfer Coefficient (h$_f$); 500, 1000, 2000, 3000 and 5000 (W/m^2.^{o}C), ΔT =(T$_f$ - T$_i$)=25 ^{o}C
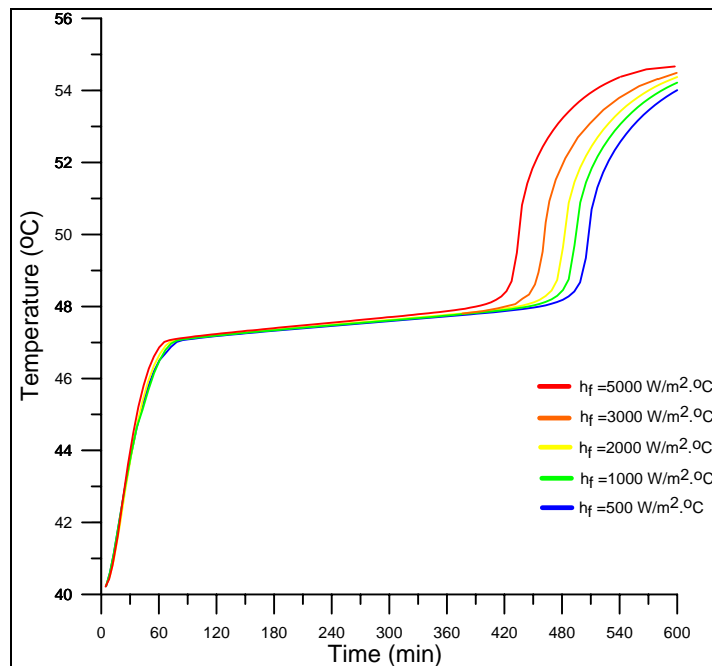
Figure 9 Temperature History during Melting Process of Paraffin (48 ^{o}C) at different Convection Heat Transfer Coefficient (h$_f$); 500, 1000, 2000, 3000 and 5000 (W/m^2.^{o}C), ΔT =(T$_f$ - T$_i$)=15 ^{o}C

After 1 hour   After 2 hour   After 3 hour
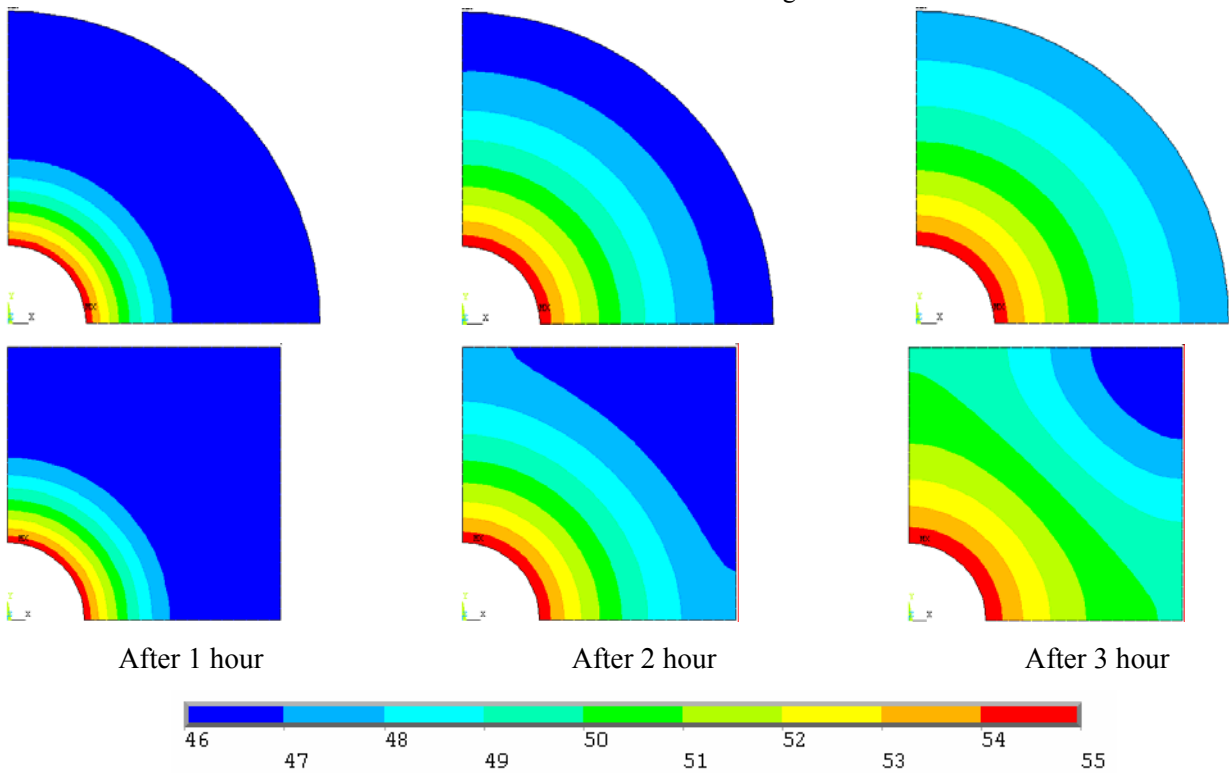
Figure 10 Temperature Distributions at Different Time during Melting Process.
PCM2/Vol.3; $\Delta T = 15\ ^oC$, $m_f = 1$ l/min.

After 1 hour   After 2 hour   After 3 hour
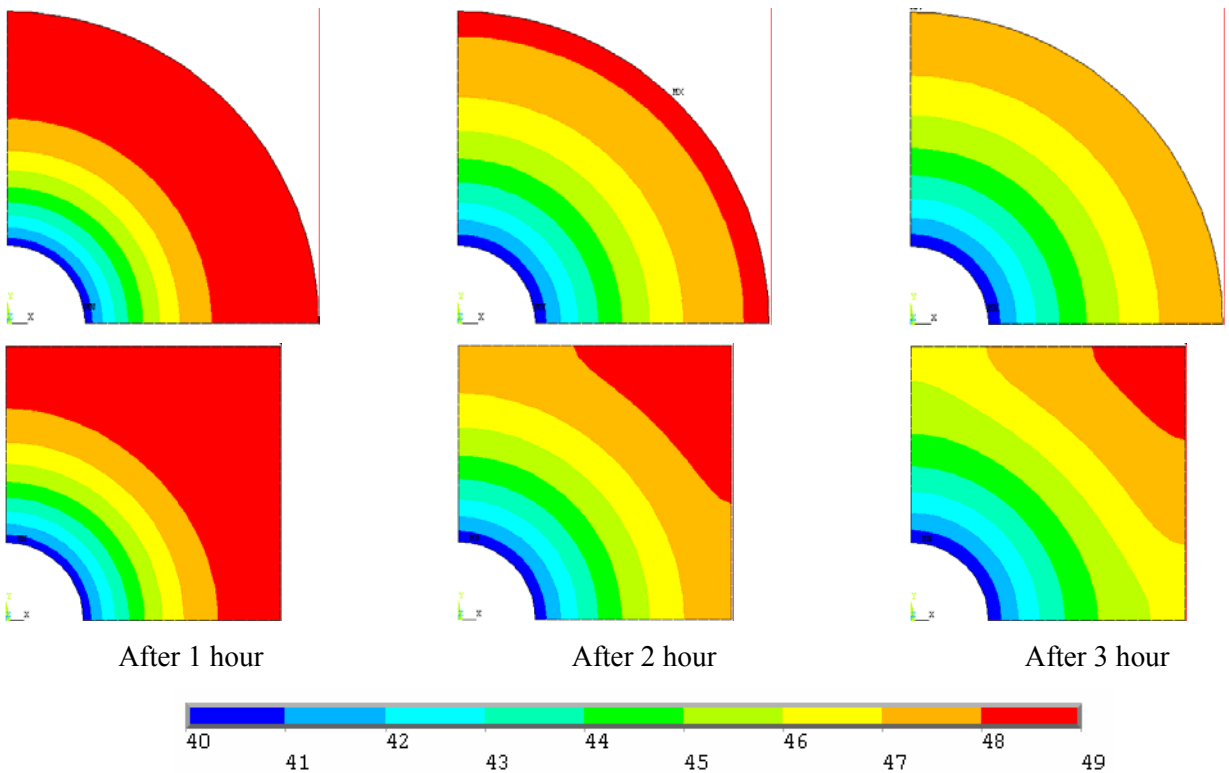
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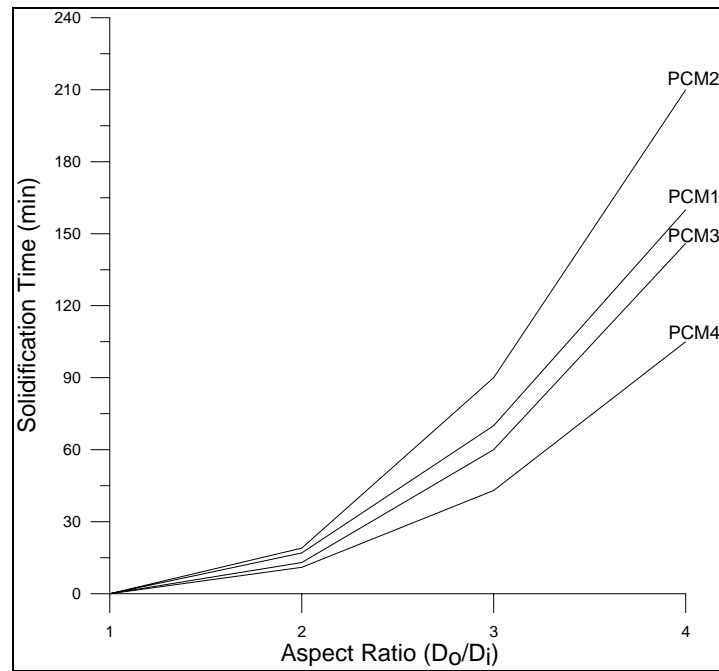
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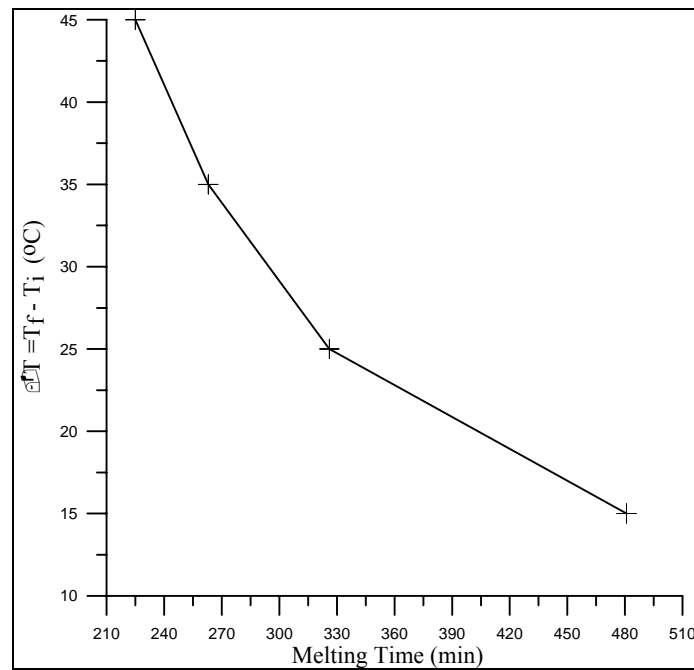
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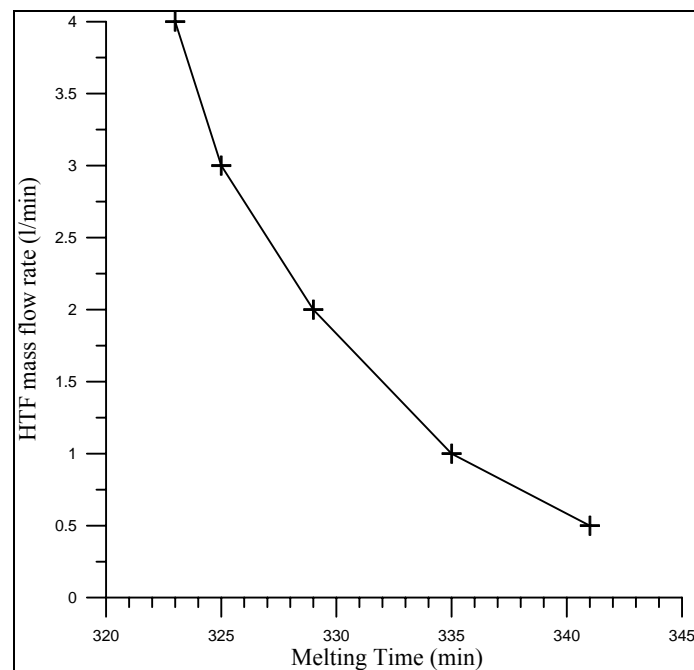
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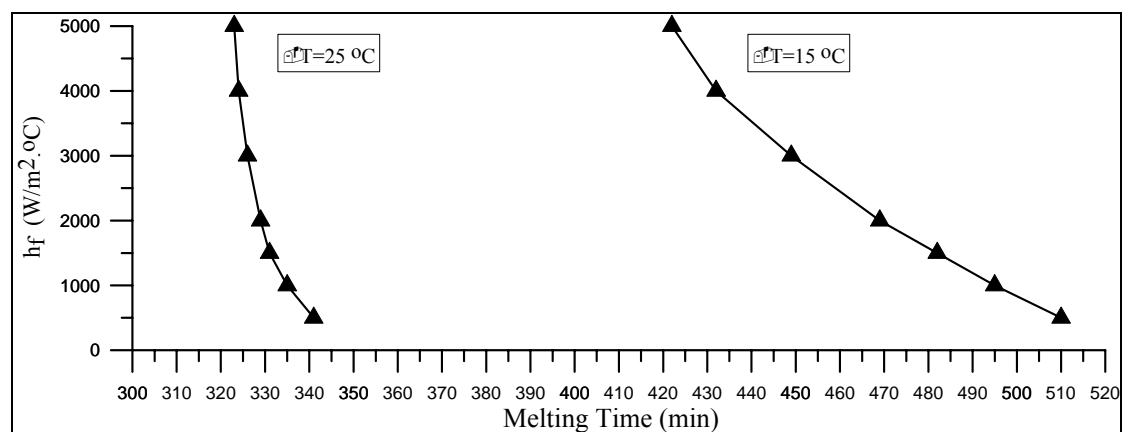
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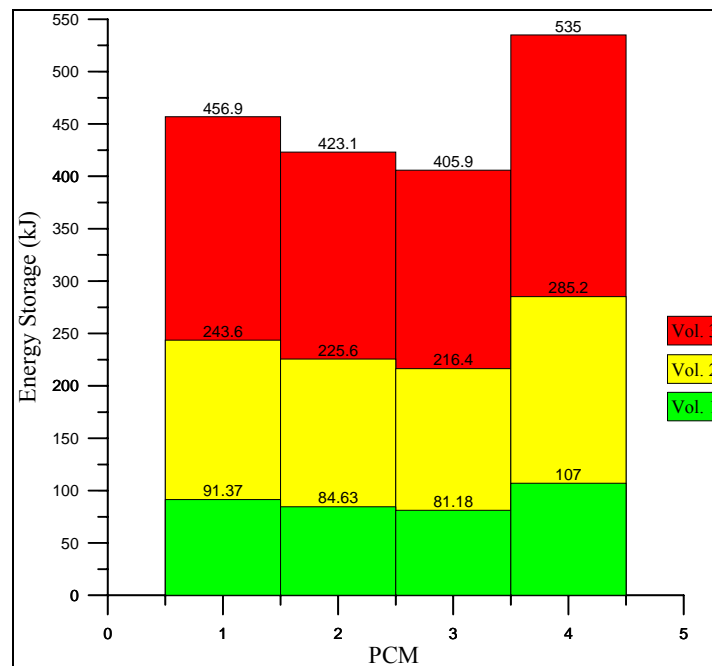
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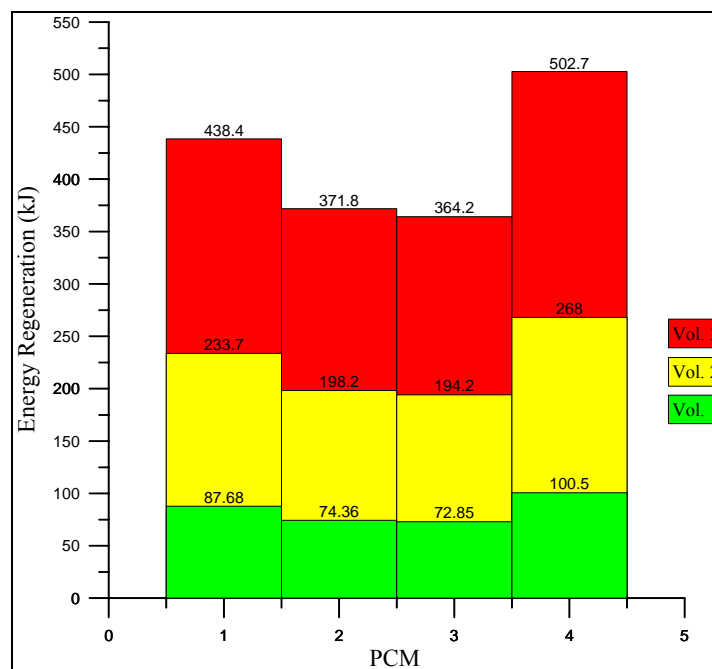
Figure 17 Energy Regeneration in various PCM at different container volume; $\Delta T = 25^{o}C$

NOMENCLATURE:

The symbols used in this paper have the following meanings:

Symbol	**Description**	**Units**
c_p	Specific heat	kJ/kg.K
D	Tube diameter	m, mm
h	Convection heat transfer coefficient	W/m^2.K
J	Jacobian	
k	Thermal conductivity	W/m.^{o}C
LH	Latent heat	kJ/kg
$\dot{m}$	Mass flow rate	kg/s, l/min
T	Temperature	^{o}C
t	Time	s, min
w	Side width	m, mm
x, y, z	Cartesian coordinates	m

Greek symbols

α'	Thermal diffusivity	m^2/s
α, β, γ, λ, σ	Transformation coefficients	
ζ, η	Body-Fitted generalized Coordinates	
ρ	Density	kg/m^3
Δ	Difference	

Subscripts

av.	Average
eff.	Effective
b	Bulk
i	Initial, inner
i, j	Grid points
f	Final, fluid
l	Liquid
m	Melting
max.	Maximum value
o	Outer
s	Solid

Abbreviations

1,2D	One, Two-dimensions
asp.	Aspect Ratio
BFC	Body-Fitted Coordinate
HTF	Heat Transfer Fluid
LHTES	Latent Heat Thermal Energy Storage
PCM	Phase Change Material
RF	Relaxation Factor
SOR	Successive Over – Relaxation
vol.	Volume

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