Jordan Journal of Mechanical and Industrial Engineering (JJMIE)

JJMIE is a high-quality scientific journal devoted to fields of Mechanical and Industrial Engineering. It is published by The Hashemite University in corporation with the Jordanian Scientific Research Support Fund.

SUBMISSION ADDRESS:

Prof. **Nabil Anagreh** , Editor-in-Chief
Jordan Journal of Mechanical & Industrial Engineering,
Hashemite University,
PO Box 330127, Zarqa, 13133 , Jordan
E-mail: jjmie@hu.edu.jo

Hashemite Kingdom of Jordan

Hashemite University

Jordan Journal of Mechanical and Industrial Engineering

JJMIE

An International Peer-Reviewed Scientific Journal

Financed by Scientific Research Support Fund

http://jjmie.hu.edu.jo/

ISSN 1995-6665

Jordan Journal of Mechanical and Industrial Engineering (JJMIE)

JJMIE is a high-quality scientific journal devoted to fields of Mechanical and Industrial Engineering. It is published by The Jordanian Ministry of Higher Education and Scientific Research in corporation with the Hashemite University.

Introduction: The Editorial Board is very committed to build the Journal as one of the leading international journals in mechanical and industrial engineering sciences in the next few years. With the support of the Ministry of Higher Education and Scientific Research and Jordanian Universities, it is expected that a heavy resource to be channeled into the Journal to establish its international reputation. The Journal's reputation will be enhanced from arrangements with several organizers of international conferences in publishing selected best papers of the conference proceedings.

Aims and Scope: *Jordan Journal of Mechanical and Industrial Engineering* (JJMIE) is a refereed international journal to be of interest and use to all those concerned with research in various fields of, or closely related to, mechanical and industrial engineering disciplines. *Jordan Journal of Mechanical and Industrial Engineering* aims to provide a highly readable and valuable addition to the literature which will serve as an indispensable reference tool for years to come. The coverage of the journal includes all new theoretical and experimental findings in the fields of mechanical and industrial engineering or any closely related fields (Materials, Manufacturing, Management, Design, Thermal and Fluid, Energy, Control, Mechatronics, and Biomedical). The journal also encourages the submission of critical review articles covering advances in recent research of such fields as well as technical notes.

Guide for Authors

Manuscript Submission:
High-quality submissions to this new journal are welcome now and manuscripts may be either submitted online or email.

Online: For online and email submission upload one copy of the full paper including graphics and all figures at the online submission site, accessed via http://jjmie.hu.edu.jo. The manuscript must be written in MS Word 2010 Format. All correspondence, including notification of the Editor's decision and requests for revision, takes place by e-mail and via the Author's homepage, removing the need for a hard-copy paper trail.

Submission address and contact:
Prof. Nabil Anagreh
Editor-in-Chief
Jordan Journal of Mechanical & Industrial Engineering,
Hashemite University,
PO Box 330127, Zarqa, 13115, Jordan
E-mail: jjmie@hu.edu.jo

Types of contributions*:* Original research papers and Technical reports

Corresponding author: Clearly indicate who is responsible for correspondence at all stages of refereeing and publication, including post-publication. Ensure that telephone and fax numbers (with country and area code) are provided in addition to the e-mail address and the complete postal address. Full postal addresses must be given for all co-authors.

Original material: Submission of an article implies that the work described has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis), that it is not under consideration for publication elsewhere, that its publication is approved by all authors and that, if accepted, it will not be published elsewhere in the same form, in English or in any other language, without the written consent of the Publisher. Authors found to be deliberately contravening the submission guidelines on originality and exclusivity shall not be considered for future publication in this journal.

Withdrawing: If the author chooses to withdraw his article after it has been assessed, he shall reimburse JJMIE with the cost of reviewing the paper.

Manuscript Preparation:

General: Editors reserve the right to adjust style to certain standards of uniformity. Original manuscripts are discarded after publication unless the Publisher is asked to return original material after use. Please use MS Word 2010 for the text of your manuscript.

Structure: Follow this order when typing manuscripts: Title, Authors, Authors title, Affiliations, Abstract, Keywords, Introduction, Main text, Conclusions, Acknowledgements, Appendix, References, Figure Captions, Figures and then Tables. Please supply figures imported into the text AND also separately as original graphics files. Collate acknowledgements in a separate section at the end of the article and do not include them on the title page, as a footnote to the title or otherwise.

Text Layout: Use 1.5 line spacing and wide (3 cm) margins. Ensure that each new paragraph is clearly indicated. Present tables and figure legends on separate pages at the end of the manuscript. If possible, consult a recent issue of the journal to become familiar with layout and conventions. All footnotes (except for table and corresponding author footnotes) should be identified with superscript Arabic numbers. To conserve space, authors are requested to mark the less important parts of the paper (such as records of experimental results) for printing in smaller type. For long papers (more than 4000 words) sections which could be deleted without destroying either the sense or the continuity of the paper should be indicated as a guide for the editor. Nomenclature should conform to that most frequently used in the scientific field concerned. Number all pages consecutively; use 12 or 10 pt font size and standard fonts.

Corresponding author: Clearly indicate who is responsible for correspondence at all stages of refereeing and publication, including post-publication. The corresponding author should be identified with an asterisk and footnote. Ensure that telephone and fax numbers (with country and area code) are provided in addition to the e-mail address and the complete postal address. Full postal addresses must be given for all co-authors. Please consult a recent journal paper for style if possible.

Abstract: A self-contained abstract outlining in a single paragraph the aims, scope and conclusions of the paper must be supplied.

Keywords: Immediately after the abstract, provide a maximum of six keywords (avoid, for example, 'and', 'of'). Be sparing with abbreviations: only abbreviations firmly established in the field may be eligible.

Symbols: All Greek letters and unusual symbols should be identified by name in the margin, the first time they are used.

Units: Follow internationally accepted rules and conventions: use the international system of units (SI). If other quantities are mentioned, give their equivalent in SI.

Maths: Number consecutively any equations that have to be displayed separately from the text (if referred to explicitly in the text).

References: All publications cited in the text should be presented in a list of references following the text of the manuscript.

Text: Indicate references by number(s) in square brackets in line with the text. The actual authors can be referred to, but the reference number(s) must always be given.

List: Number the references (numbers in square brackets) in the list in the order in which they appear in the text.

Examples:

Reference to a journal publication:

[1] M.S. Mohsen, B.A. Akash, "Evaluation of domestic solar water heating system in Jordan using analytic hierarchy process". Energy Conversion & Management, Vol. 38 (1997) No. 9, 1815-1822.

Reference to a book:

[2] Strunk Jr W, White EB. The elements of style. 3rd ed. New York: Macmillan; 1979.

Reference to a conference proceeding:

[3] B. Akash, S. Odeh, S. Nijmeh, "Modeling of solar-assisted double-tube evaporator heat pump system under local climate conditions". 5th Jordanian International Mechanical Engineering Conference, Amman, Jordan, 2004.

Reference to a chapter in an edited book:

[4] Mettam GR, Adams LB. How to prepare an electronic version of your article. In: Jones BS, Smith RZ, editors. Introduction to the electronic age, New York: E-Publishing Inc; 1999, p. 281-304

Free Online Color : If, together with your accepted article, you submit usable color and black/white figures then the journal will ensure that these figures will appear in color on the journal website electronic version.

Tables: Tables should be numbered consecutively and given suitable captions and each table should begin on a new page. No vertical rules should be used. Tables should not unnecessarily duplicate results presented elsewhere in the manuscript (for example, in graphs). Footnotes to tables should be typed below the table and should be referred to by superscript lowercase letters.

Notification: Authors will be notified of the acceptance of their paper by the editor. The Publisher will also send a notification of receipt of the paper in production.

Copyright: All authors must sign the Transfer of Copyright agreement before the article can be published. This transfer agreement enables Jordan Journal of Mechanical and Industrial Engineering to protect the copyrighted material for the authors, but does not relinquish the authors' proprietary rights. The copyright transfer covers the exclusive rights to reproduce and distribute the article, including reprints, photographic reproductions, microfilm or any other reproductions of similar nature and translations.

Proof Reading: One set of page proofs in MS Word 2010 format will be sent by e-mail to the corresponding author, to be checked for typesetting/editing. The corrections should be returned within **48 hours**. No changes in, or additions to, the accepted (and subsequently edited) manuscript will be allowed at this stage. Proofreading is solely the author's responsibility. Any queries should be answered in full. Please correct factual errors only, or errors introduced by typesetting. Please note that once your paper has been proofed we publish the identical paper online as in print.

Author Benefits:

No page charges: Publication in this journal is free of charge.

Free offprints: One journal issues of which the article appears will be supplied free of charge to the corresponding author and additional offprint for each co-author. Corresponding authors will be given the choice to buy extra offprints before printing of the article.

JJMIE

Volume 8, Number 2, April 2014
ISSN 1995-6665

Jordan Journal of Mechanical and Industrial Engineering

JJMIE

Volume 8 Number 2, April. 2014
ISSN 1995-6665
Pages 50 - 55

Jordan Journal of Mechanical and Industrial Engineering

Parametric Coordination and Simulation Study on Nonstandard Spur Gears

Qian tang, Xiaofeng Jin*, Qiulei Fan

State Key Laboratory of Mechanical Transmission, Chongqing University, Chongqing 400030, P.R.China

Abstract

This paper presents the parametric collaborative rules of nonstandard spur gear in order to improve the bending strength. For numerical work, equation between fillet radius and pressure angle is established according to the gearing theory. Also, the mechanism of action that pressure angle, fillet radius and addendum coefficient have on the bending strength is investigated. So it is shown how pressure angle, fillet radius and addendum coefficient affect the bending strength. Based on that, coordinated figures among the gear parameters and the collaborative design for stronger bending strength of nonstandard spur gears are proposed. Furthermore, bending stress of gears with different parameters are simulated and compared with the theoretical computing values to support the conclusion.

Keywords: *Spur Gears; Bending Strength; Pressure Angle; Fillet Radius; Addendum Coefficient.*

Nomenclature

α :pressure angle (°)
h_a :addendum
h^*_a :addendum coefficient
m :module(mm)
Z :number of teeth
r_p : pitch radius (mm)
c : clearance
c^* : clearance coefficient
r_ρ : fillet radius(mm)
F_n :normal net force on the involute curve(N)
F_t : tangential force(N)
F_r : radial force (N)
K : load coefficient
b :tooth width(mm)
Y_F :tooth form factor
Y_S : stress correction factor
α_p : pressure angle of rank cutter (°)
$r_{\rho\max}$: maximum of fillet radius(mm)

1. Introduction

Nonstandard spur gears have broader applications compared to standard gears due to the flexible design and manufacture. Furthermore, standard gears cannot meet the needs of various operating conditions because of the limited carrying capacity on tooth root. So in many cases they need to be designed into a nonstandard form in order to improve the mechanical performance, such as improving addendum, changing tooth thickness, making pressure angle not be 20 degree, etc. The performance of nonstandard spur gears will be far more excellent than that of the standard gears if properly designed.

Recently, there have been some efforts made to widen the application of nonstandard spur gears. Mabie H. [1] investigated the mathematical model of processing nonstandard spur gears by hob. Wu Jize [2], Fang Zongde [3] and Jiang Xiaoyi [4] studied the equations of fillet curves, the stress concentration and the influence which fillet has on the tooth bending strength. C. Spitas and Spitas V.[5; 6] investigated the method of processing nonstandard spur gears by standard cutter, and analyzed the effect the achieved circular fillet and trochoid fillet curve have on tooth bending strength. ODA Satoshi [7; 8] developed the rule of tooth deformation under standard pressure angle based on the experimental method. Handschuh R.F. [9], Thirumurugan R. [10] and F.M Khoshnaw [11] investigated the performance between different pressure angle gears. Hidaka [13] and Shuting Li [14] investigated the effect of the addendum change on contact strength, bending strength and basic performance

* Corresponding author. e-mail: jinxfe@163.com.

based on photoelastic and finite element analysis. S. Baglioni and F. Cianetii [15] analyzed spur gears' efficiency through two different approaches for friction coefficient calculation along the line of action. The authors always considered only a single factor when studying the relations between parameter and bending strength in their research, ignoring the relations between the parameters.

This paper proposes a collaborative design method for strengthening the bending strength of nonstandard spur gears by investigating the effect that pressure angle, fillet radius and addendum coefficient have on bending strength. It is hoped that the study will provide guidance for nonstandard spur gears design.

2. Effect of Parameters on Bending Strength

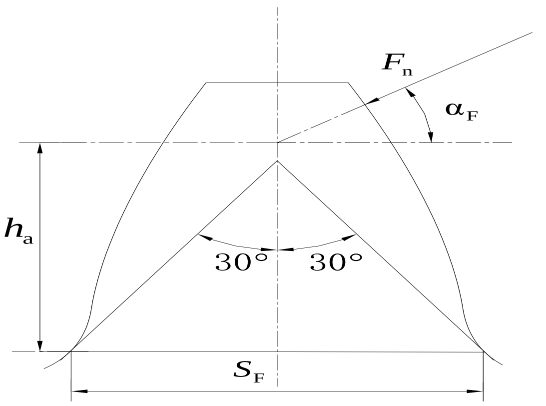
2.1. Bending Stress Calculation Model

The ISO method is used to calculate the bending stress of nonstandard spur gears, the dangerous section is determined by the $30°$ tangent method, as shown in Figure 1. If we assume gear as a cantilever beam, the normal force which acts on the involute can be divided into two parts: The tangential force that makes gear bending, and the radial force that makes gear shearing, during the power transmission.

strength of gear is as follow:

$$\sigma = \frac{KF_t Y_F Y_S}{bm} \tag{1}$$

Where, Y_F and Y_S are complicated to calculate for the many intermediate parameters contained [4]. Some of the intermediate parameters need that the iterative computing be solved. So the program calculation method is used.



Figuer 1. Computing model of bending strength

2.2. Effect of Pressure Angle on Bending Strength

For gears, tooth profile will differ with the shape of the rack cutter. The pressure angle of standard rack cutter is 20 degree, but it is only a compromise value. For the gear design of some special purpose (design of nonstandard spur gear), it is not the best value.

According to the computing equation of tooth bending stress (as show in Eq.(1)) and combined with the stress calculation model (as shown in Figure 1), bending strength is calculated under pressure angles ($14.5°, 16°, 22.5°, 25°, 28°$) and a suitable range of normal loads. In order to have a president value to confirm that the computing results are suitable, the parameters of the gear are chosen according to reference [16] as shown in Table 1.

Table 1. Parameters of nonstandard spur gears

Module (mm)	Tooth width (mm)	Load coefficient	Number of teeth
6	17	1.3	32

Based on the MATLAB software, a program for bending stress calculation is written. Bending stress that varies with the normal load is devised under 5 sets of pressure angle as shown in Figure 2. The vertical line in the graph expresses the rule that bending stress varies with the pressure angle. It can be drawn from the chart that bending stress increases with the increase of the load, and the changing trend does not change when the pressure angle differs. The one with smaller pressure angler has larger gradient. This means that the load has a stronger influence on bending stress under high pressure angler. Bending stress decreases with increasing the pressure angle and the variation curve is almost linear; thus, increasing the pressure angle helps to improve the bending strength. When the load is large, it obviously increses the bending strength, if increasing of pressure angle is applied.

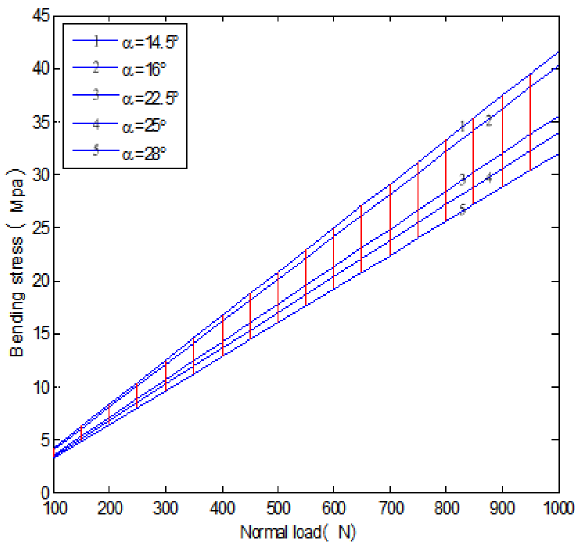


Figure 2. Relation of bending stress and normal load

2.3. Effect of Fillet on Bending Strength

There are several kinds of fillets for nonstandard spur gears. Different shape of fillet of rack cutter processes out different gear fillet. The standard value of cutter fillet radius is 0.38*m; otherwise the processed gear is a nonstandard gear. Because the dangerous section occurs in the gear fillet, so it has a great significance for improving the bending strength.

Parameters of standard rack cutter are shown in Figure 3.

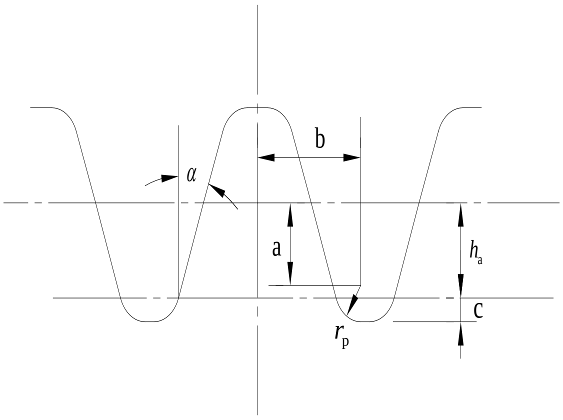


Figure 3. Tooth profile of standard rack cutter.

According to the geometrical relationship of gear [2], we can learn that the relation between each parameter is as follows.

$$a = h^*_a m + c^* m - r_\rho \quad (2)$$

$$b = \frac{\pi m}{4} + h^*_a m \tan\alpha + r_\rho \cos\alpha \quad (3)$$

$$r_\rho = \frac{c^* m}{1 - \sin\alpha} \quad (4)$$

In a standard rack cutter, the fillet arc is tangent to both the tooth profile and the addendum line. So if the tip clearance is given, the fillet radius will be a fixed value and improper selection may affect the gear bending strength. So it is necessary to explore the relation between the cutter fillet radius and the pressure angle. From reference [2], we can learn that the equation that expresses top clearance with pressure angle and cutter fillet radius is given by Eq. (5).

$$c = r_\rho (1 - \sin\alpha) \quad (5)$$

Figure 4 shows the relation between bending stress and cutter fillet. It is achieved by calculating the bending stress with a proper range of the cutter fillet radius based on the MATLAB software. Three curves in Figure 4 indicate that there are three different pressure angle values. From the graph, we can see that the variation trend is consistent between the bending stress and the cutter fillet radius. The bending stress decreases with the increase of the cutter fillet radius, and the reduction slows down with the increase of the cutter fillet radius (decreases in the radius of curvature of curve), which illustrates that the increase of the cutter fillet radius can enhance the bending strength of the processed gear. But the increase of the cutter fillet radius leads to the increase of the tip clearance that causes raising the tooth height which can lead to an increase in the bending arm. It will weaken the mechanical properties of gear. Therefore, a blind pursue of the high fillet radius is not recommended.

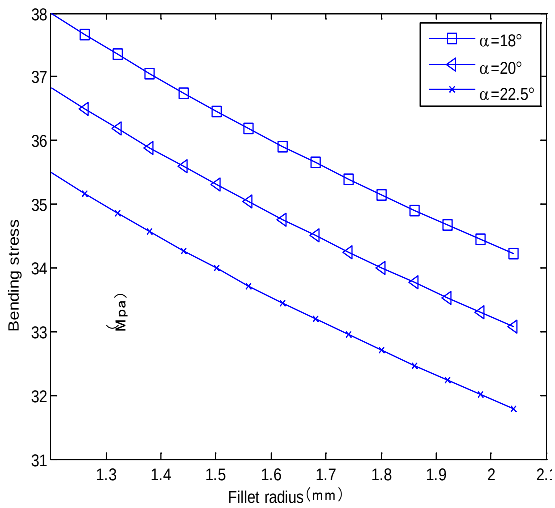


Figure 4. Relation of the bending stress and fillet radius of rack cutter.

3. Bending Strength of Nonstandard Spur Gears

3.1. Parameters Collaborative Rule of Nonstandard Spur Gears

Based on the above analysis, the bending strength of nonstandard spur gears has a close contact among rack cutter fillet radius, pressure angle and addendum coefficient. The gear shape and the mechanical properties will change with these three parameters. So coordination between these three parameters is helpful for improving the carrying capacity of gear transmission.

According to geometry of tooth profile of rack cutter (as shown in Figure 3), the cutter fillet radius will reach the maximum value when the cutter fillet becomes round. Change of the pressure angle will affect the fillet radius of rack cutter when the module is in certain cases, and the pitch remains unchanged. The greater pressure the angle has, the smaller tooth width of the addendum circle is; the limiting of fillet radius will also decrease.

From the geometrical relationship of gear as (shown in Figure 3), when the cutter fillet becomes round, fillet radius value of rack cutter can be computed with:

$$r_{\rho\max} = \frac{\pi m - 4h^*_a m \tan\alpha}{4\cos\alpha} \quad (6)$$

According to Eq.(6), the bending strength is computed by MATLAB software program under limited value of the fillet radius. The relation graph between the bending stress and pressure angle is acquired under the maximum value of the fillet radius, as shown in Figure 5. It can be derived from Figure 5 that the gear has the strongest bending strength when the pressure angle is 23.5 degree. If the pressure angle keeps increasing, the bending strength will decrease. Comparing the maximum fillet radius with the standard case, it can be found that distinct differences exist between the two cases: the case of maximum fillet radius, on the one hand, bending strength increased because of the increase of the fillet radius which, on the other hand, causes the increase of the tooth height, and then weakens the gear bending strength. That is why the bending strength weakens with the increase of the pressure angle after 23.5 degree. So for the small pressure angle gear, it can effectively improve the bending strength with rational allocation of the addendum coefficient.

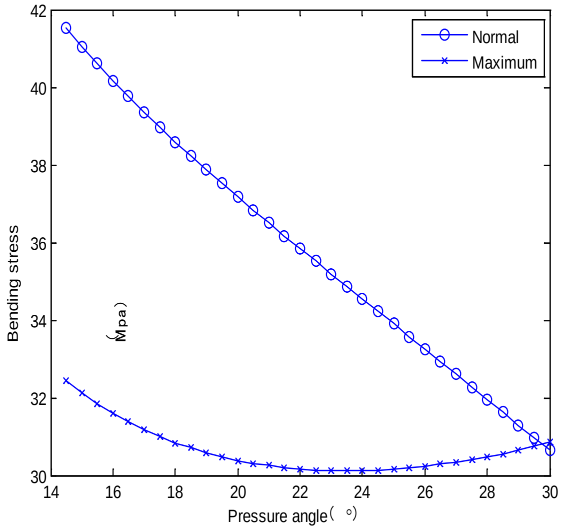


Figure 5. Relation between pressure angle and bending stress with standard and maximum fillet

3.2. Parameters Coordination of Nonstandard Spur Gears

In sum, the effect of the pressure angle on bending stress is a complex process based on the findings of the present study. The change of pressure angle will influence many other parameters, which further affects the bending strength. So the coordination of pressure angle, cutter fillet radius and the addendum coefficient is investigated. Bending stress decreases with the decrease of the addendum coefficient, but then it increases with the decrease of the addendum coefficient under a small pressure angle ($\alpha = 14.5°$, $\alpha = 16°$) and fillet radius based on MATLAB software calculation results. For big pressure angle ($\alpha = 22.5°$, $\alpha = 25°$, $\alpha = 28°$), the bending stress decreases with the increase of the addendum coefficient. The recommended value of collaboration of the pressure angle, fillet radius and addendum coefficient is given in Figure 6 and Figure 7.

Figure 6 shows the coordinated relation of addendum coefficient and cutter fillet radius in small pressure angle, if the pressure angle is 14.5 degree, when the fillet radius is 0.4*m and the addendum coefficient is recommended to 0.9. We also proposed that in the case of small pressure angle, a larger value of fillet radius is recommended. Figure 7 shows the relation between fillet radius and addendum coefficient under high pressure angle when the tooth height is compensated to standard value. The range of the fillet radius will decrease in a large pressure angle. The recommended parameters of the pressure angle, fillet radius and addendum coefficient (Figure 6 and Figure 7) can improve the gear bending strength.

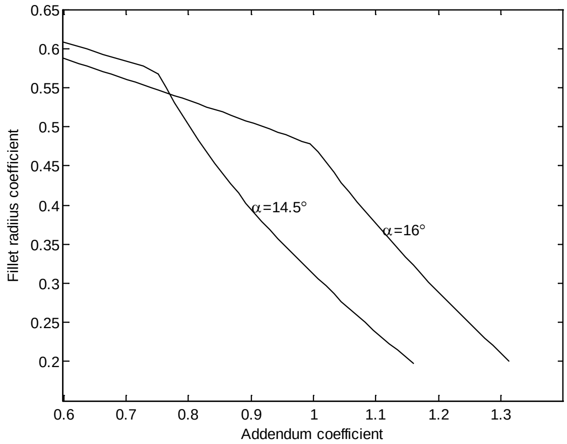


Figure 6. Relation of fillet radius and addendum coefficient in small pressure angle.

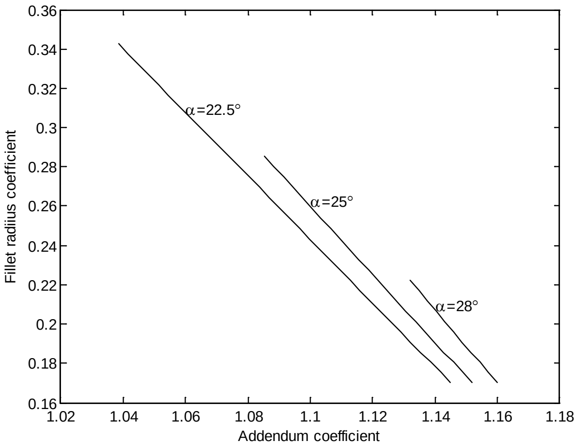


Figure 7. Relation of fillet radius and addendum coefficient in big pressure angle.

4. FEM Analysis

On the choice of pressure angle, cutter fillet radius and addendum coefficient, the orthogonal experiment method, which involves using a neatly arranged orthogonal table to integrate design, for comprehensive comparisons and statistical analyses in order to achieve better production conditions through a few number of experiments, is adopted. There may be many factors, and every factor can have several different values that influence the parts we studied. The number of the values is experiment levels. Fifteen finite element analysis models for bending stress computing are established by three factors and five levels orthogonal table [12], made by mathematicians. Then, according to the orthogonal table, different combinations of gear parameters are determined. The factor level of the orthogonal experiment is shown in Table 2.

Table 2. Basic parameters for gear design

Level	Factor		
	Pressure angle (°)	Fillet radius (mm)	addendum coefficient
1	14.5	0.45*m	0.85
2	16	0.4*m	1.08
3	20	0.38*m	1
4	22.5	0.3*m	1.07
5	25	0.26*m	1.1

The simulation analysis model of nonstandard gear bending stress is established as shown in Figure 8. To achieve the FEM model, a static/general step is used in Abaqus software. Element type is C3D8R and 32616 elements are meshed. According to the finite element analysis, the stress nephograms is derived as shown in Figure 9.

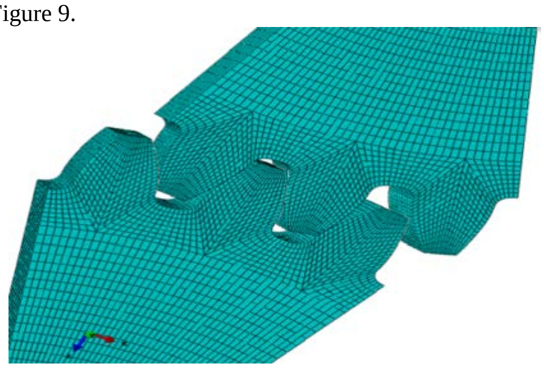


Figure 8. FEM model of nonstandard spur gears.

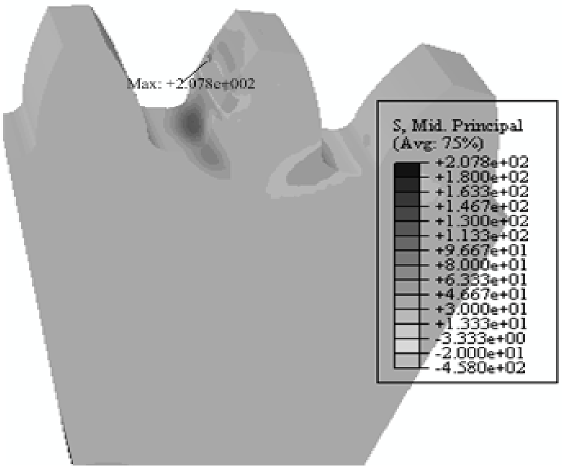


Figure 9. Bending stress nephogram of nonstandard spur gears.

From the FEA results of the bending stress simulation and theoretical calculation, we can conclude that gears with a larger pressure angle have a relatively smaller bending stress, and those with bigger fillet radius have better mechanical properties. The bending stress of nonstandard spur gears, with which their pressure angle, fillet radius and addendum coefficient are chosen according to Figure 6 and Figure 7, are smallest than the others. For example, the bending stress of which the pressure is 16 degree, fillet radius is 0.4*m and addendum coefficient is 1.08, reduced almost 31.2% compared with the same series of gears with the same pressure angle.

Table 3. Design parameters and FEA results of nonstandard spur gears

Sequence number	Pressure angle (°)	Fillet radius (mm)	Addendum coefficient	Bending strength（MPa）		Relative error (%)
				FEA results	Theoretical calculation results	
1	14.5	0.45*m	0.85	235.3	233	0.99
2	16	0.4*m	1.08	192.1	188	2.19
3	20	0.38*m	1	207.8	211	1.52
4	22.5	0.3*m	1.07	136.9	123	11.3
5	25	0.26*m	1.1	152.5	161	5.28
6	14.5	0.4*m	1	290.1	275	5.49
7	16	0.38*m	1.07	266.7	262	1.79
8	20	0.3*m	1.1	231.2	219	5.57
9	22.5	0.26*m	0.85	154.2	148	4.19
10	14.5	0.38*m	1.1	301.0	282	6.74
11	16	0.3*m	0.85	285.4	273	4.54
12	20	0.26*m	1.08	241.5	259	6.76
13	14.5	0.3*m	1.08	304.1	300	1.36
14	16	0.26*m	1	241.9	246	1.67
15	14.5	0.26*m	1.07	328.6	320	2.69

5. Conclusion

From the research on the relation of parameters and bending stress and the analysis of the collaborative relations, it is concluded that:

(1) Increasing the fillet radius can enhance the bending strength during the nonstandard spur gears design, but it causes a tooth height increase, which will have a negative impact on the bending strength. Parameter collaborating of nonstandard spur gears is needed to significantly improve the mechanical properties.

(2) Bending stress decreases with the decrease of the addendum coefficient, but it then increases with the decrease of the addendum coefficient under small pressure angle. But under high pressure angle, the bending stress decreases with the increase of the addendum coefficient.

(3) Parametric coordination of the pressure angle, fillet and addendum can improve the bending strength of nonstandard spur gears. Furthermore, the values of the parameters which can improve the carrying capacity of nonstandard spur gears are given.

(4) The FEA model is established based on the collaborative relation graph. The comparison between FEA results and theoretical values displays the availability of the results which demonstrate the feasibility of parameter collaborating.

Acknowlengment

The authors thank the Natural Science Foundation of China (grant number 51175522) and the Key Scientific and Technological Project of Chongqing (grant number cstc2012gg-yyjs70011).

References

[1] Mabie.H, Rogers.C. “Design of Nonstandard Spur Gears Cuting by Hob”. Mechanism & Machine Theory, Vol. 25, 1990, 635-644.

[2] WU Jize, WANG Tong.Tooth Root Transition Curve and Tooth Root Stress. Beijing: National Defense Industry Press; 1989.

[3] Fang Zongde. “Design of High Strength of Gear Fillet with Boundary Element Method”. Journal of Mechanical Engineering, Vol. 26, No.5, 2001, 13-19.

[4] Jiang Xiaoyi, “Effective Measures to Improve Gear Bending Strength with Increasing Fillet Radius”. Journal of Mechanical Engineering, Vol. 19, 1992, 78-85.

[5] Spitas.V, “Four-parametric Design Study of the Bending Strength of Circular-fillet Versus Trochoidal-fillet in Gear Tooth Design Using BEM”.Mechanics Based Design of Structures and Machines, Vol. 35, 2007, 163-178.

[6] Spitas.C., Spitas.V., “Effect of Cutter Pressure Gngle on the Undercutting Risk and Bending Strength of 20 Involute Pinions Cut with Equivalent Nonstandard Cutters”. Mechanics Based Design of Structures and Machines, Vol. 36, 2008, 189-211.

[7] ODA Satoshi, “Effects of Pressure Angle on Tooth Deflection and Root Stress”. Bulletin of JSME, Vol. 29, 1986, 3141-3148.

[8] ODA Satoshi, “Root Stresses of Helical Gears with Higher Ressure Angle”. Bulletin of JSME, Vol. 29, 1986, 3149-3156.

[9] Handschuh R. F., A. J. Zakrajsek, “High Pressure Angle Gears: Comparison to Typical Gear Designs”. Journal of Mechanical Design, Vol. 133, No.11, 2011, 45-56.

[10] Thirumurugan R. , G. Muthuveerappan, “Maximum Fillet Stress Analysis Based on Load Sharing in Normal Contact Ratio Spur Gear Drives”. Mechanics Based Design of Structures and Machines, Vol. 38, 2010, 204-226.

[11] Khoshnaw F. M. , N. M. Ahmed, “The pressure angle effects of spur gears on stress concentration factor”. Engineering Compu- tations, Vol. 26, 2009, 360-374.

[12] WANG Wei , YUN Chao, “Orthogonal Experimental Design to Synthesize the Accuracy of Robotic Mechanism”. Journal of Mechanical Engineering, Vol. 45, No.11, 2009, 21-22.

[13] Hidaka Teruaki, “Effect of Addendum Modification Coefficient on Bending Strength of Internal Gear”. Bulletin of JSME, Vol. 28, 1985, 329-336.

[14] Shuting Li, “Effect of Addendum on Contact Strength, Bending Strength and Basic Performance Parameters of a Pair of Spur Gears”. Mechanism and Machine Theory, Vol.43, 2008, 1557-1584.

[15] S.Baglioni , F.Cianetii, “Influence of the Addendum Modification on Spur Gear Efficiency”. Mechanism and Machine Theory, Vol.49, 2012, 216-233.

[16] Zhang Zhan, Liu Shubing. Practical gear design and calculation Manual. In: Zhang Zhan, Zhang Guorui, Calculation of load capacity of cylindrical gears, editors. Beijing: Machinery Industry Press; 2010, p. 197-220.

JJMIE

Volume 8 Number 2, April. 2014
ISSN 1995-6665
Pages 56 - 65

Jordan Journal of Mechanical and Industrial Engineering

Effect of Asymmetric Branches on Solid Particles Distribution in Central Gas Stations (CGSs)

M. Bakhshesh[1], E. Goshtasbi Rad[1*], M. Mehrvar[2]

[1] *Department of Mechanical Engineering, Shiraz University, Shiraz, Iran*
[2] *Department of Chemical Engineering , Ryerson University, 350 Victoria Street, Toronto, Ontario*

Abstract

Natural gas flows always contain solid particles in various points of transport and distribution lines. These particles can accumulate where the passages become narrow, whereas in regulators and gas burner devices, this might cause some problems. Therefore, natural gas should be filtered and then decompressed in central gas stations (CGSs) before entering into the pipelines of city or residential areas. Therefore, the kind and the number of filters should be determined, depending on particle accumulation.

In the present work, Lagrangian method is used for studying the accumulation and deposition of solid particles in a pipeline with asymmetric branches. Moreover, the effect of some parameters, such as Stokes number, Reynolds number, and symmetric branches on the amount of outlet particle accumulation, is investigated.

The effect of curvature ratio on the penetration of particles in a 90^o bend as well as the effect of Reynolds number upon particle deposition is evaluated and the results have been compared with the available data from the open literature. Finally, the dependence of volume portion of particles is shown with flow rate. The results show that the dependency is higher at high flow velocities. In all current cases, particles do not affect the flow field due to their low volume portion.

Keywords: *Two-Phase Gas-Solid Flows, Asymmetry Branch, Deposition, and Penetration Particles.*

1. Introduction

Two phase gas-solid flows can be detected in various engineering applications and industrial process. Solid particles can cause a lot of damage to transport pipeline equipment and central gas stations due to corrosion within gas pipelines. One major approach for removing solid particles from gas is using dry gas filters. Distribution of solid particles in central gas station is non-uniform because of asymmetric branches.

Many studies have been carried out to characterize the penetration of aerosol through bends. Cheng and Wang developed a model based on an analytical laminar flow solution to investigate the behavior of aerosol particles in 90^o bends. They proposed a correlation for particles penetration as a function of the Stokes number and curvature ratio [1].

Carne and Evanes utilized a numerical method to predict the behavior of aerosol particles in a laminar air flow of 90^o bend and curvature ratios from 4 to 20 and their results showed reasonable agreement with those of Chang and Wang [2].

Cheng and Wang re-examined the deposition of particles in pipe bends. They concluded that in the laminar flow regime the aerosol particle deposition was mainly a function of Stokes number and Reynolds number for different curvature ratios [3]. However, since the flow regime in transport systems with bends is usually turbulent, their model is not generally applicable.

Pui experimentally evaluated the deposition of aerosol particles in 90^o bends for different Reynolds numbers and curvature ratios. For turbulent flow, it was assumed that the penetration does not depend on neither curvature ratio nor Reynolds number and presented a correlation for predicting the aerosol particle in 90^o bend [4].

Tsai and Pui used a three-dimensional numerical model to examine the aerosol particle deposition for laminar flow in a pipe with a 90^o bend. They observed significant variation in the deposition efficiency by changing the amount of curvature ratio. They also witnessed the effect of the inflow velocity profile on the deposition efficiency. For parabolic inlet velocity profile, their results could be confirmed with the results of Cheng and Wang [5].

One of the first numerical studies of the particle motion in a horizontal pipe was performed by Ottjes who considered the effects of Magnus lift force and inelastic particle-wall collisions [6]. Moreover, more complex geometries were considered by Tsuji and Morikaw who utilized a numerical simulation of gas-solid flow in a

* Corresponding author. e-mail: goshtasb@shirazu.ac.ir.

horizontal channel [7]. In all the above investigations, the effect of particles on the gas flow has been neglected.

A remarkable amount of numerical studies on particulate flows in pipes have been done in 1991. Three-dimensional solutions of horizontal pneumatic conveying were presented for particle loading ratios between 1 and 10 including two-way coupling and wall impact effect of non-spherical particles. Collisions of particles, recognized as an effective and important parameter at high loading flow, has not been considered in their work. Flow turbulence effects on the particle motion could be neglected due to the large size of particles [8].

An effort was made to predict the pressure drop in horizontal pneumatic conveying of coarse particles by Tashiro [9]. Tashiro use an Euler-Lagrange approach and considered the effect of the lift force, inter particle collisions, and particle-wall collisions without roughness. However, a two-way coupling for modeling of particle behavior has not been considered. Further, the results have shown considerable differences with experimental correlations.

Various experimental studies have been done by Hurber and Sommerfeld [10] and Yilmaz and Levey [11] on dust conveying systems with solids mass loading of larger than 0.3. It has been observed that the particle behavior in such flow systems is partly complex and strongly affected by the particle size, the wall roughness, the conveying velocity, and the radius of the bend. However, the low limit of gas-solid flow dilution in these models has not been elucidated.

Lumley estimated that particle-particle interaction is negligible for spherical particles with volumetric concentration below 0.3% [12].

At low Reynolds numbers, the fluid and particle velocities are equal for the neutrally buoyant particles [13, 14].

Hajji and Pascal investigated the dispersion of heavy particles in homogeneous isotropic turbulent gas-solid flows. The Lagrangian approach was used for the simulation of particles' dispersion and the effects of particles' inertia and drift velocity on fluid turbulence were investigated [15].

In order to study the dispersed gas-solid flows in pipe systems, Hurber and Sommerfeld made an Eulerian/Lagrangian approach. They considered the effects of important parameters such as turbulence, two-way coupling, particle transverse lift force, particle-wall collisions including wall roughness and inter particle collisions [16].

Sommerfeled, Lain and Kussin used Reynolds stress model for studying the particle motion in a horizontal channel flow and observed that for high mass loading of particles, wall roughness and inter–particle collisions have a significant impact on the particle behavior [17].

The motion of solid particles in horizontal and vertical pipes was investigated by Kuan and Schwarz. Their study confirmed the role of drag coefficient and inlet conditions in the calculations of particle track in a vertical duct. Furthermore, in the analyzing a two-phase flow in a horizontal duct, it was shown that the gravitational force has the dominant influence on the distribution of particles [18].

Kuan investigated single and two phase flows in a 90^o bend. In a simulation, gas turbulence was solved for differential Reynolds stress models, whereas a Lagrangian approach was used to predict particle tracks. The effects of some important parameters such as one-way coupling, turbulence dispersion, pressure gradient effects, transverse lift force, and surface roughness were considered. Two major conclusion of his study were that fine particles mainly tend to follow the gas motion more firmly and gas flow near the outer wall of bend decelerates in the presence of adverse pressure gradient as well as accelerates under the influence of favorable pressure gradient [19].

Dehbi studied particle-turbulence interactions close to walls of 90^o bend, where anisotropic effects are considerable. Flow field was simulated with the FLUENT and particle dispersion in turbulent boundary layer flows was analyzed. The results confirmed that for smaller particles, inertia effects are reduced. Therefore, the model offers more accurate prediction for turbulent field in the boundary layer [20].

Hadinoto and Curits examined the effect of Reynolds number on the gas-phase turbulence in a vertical downward pipe. Moreover, they investigated the effect of particles on the turbulence modulation. They concluded that in the presence of high inertia particles at a low particle loading, the intensity of gas-phase turbulence in the pipe core is increased with increasing Reynolds number [21].

Mando and Lightstone studied the effect of particles on the turbulence equations. They utilized Eulerian/Lagrangian approach for the source terms. Their results were compared with the standard and consistent models obtained data as well as with experimental results [22].

Ono and Kimura used two types of elbows with different curvature ratios to study the interaction between flow separation and secondary flow due to the elbow curvature for high Reynolds numbers. They concluded that the flow separation always formed in the short-elbow while secondary flows intermittently occurred in the long-elbow case [23].

Lain and Sommerfeld investigated pneumatic conveying of spherical particles both in horizontal ducts and circular pipes. The Eulerian-Lagrangian approach was used for three dimensional numerical solution. They employed k–ε and Reynolds Stress models to solve flow field in a pipe with high particle volumetric percent and demonstrated that inter-particle collisions have a significant effect on velocity profile in a pipe. Furthermore, many research papers showed that the wall collisions frequency is considerably higher in the pipe in comparison with the channel [24].

The purpose of the present study is to evaluate the effects of curvature ratio, Reynolds and Stokes numbers on deposition of particles in 90^o bends to validate the computational assumption and to investigate asymmetric branches upon distribution of particles in a pipe line. To do this, the geometry of an asymmetric pipeline system is drawn. Afterwards, the structural grid is generated in the computational domain and flow field is simulated. Finally, particles are injected into the flow field.

To study the grid independency, meshes with different resolutions are generated. Since Brownian motion and diffusion phenomenon do not affect the behavior of particles and their deposition remarkably, these parameters are neglected. Since in dilute two phase flows drag and gravity forces are effective parameters [25], these parameters are considered in this study. Since volumetric concentration of particles in the flow field is below of 0.1%, particle-particle interaction is neglected and the assumption of one way coupling between particles and fluid is used [20]. This means that the flow field is not affected by particles. Therefore, after solving the flow field, the behavior of particles is investigated by using the Lagrangian method. It is worth mentioning that, in Eulerian-Lagrangian approach, the fluid phase is considered as a continuum media by solving the time-averaged Navier-Stokes equations, while the dispersed phase is solved by tracking a large number of particles through the computational domain. This approach is the most accurate way to predict the dispersion of particles in the flow field [26].

The dispersion of particles due to turbulence in the fluid phase is predicted by using stochastic tracking model which includes the effect of instantaneous turbulent velocity fluctuations on the particles trajectories.

The most important parameters in the problem of flow through bends with circular tubes are Reynolds number and curvature of the bend. These two parameters characterize dimensionless Dean number that is defined as:

$$De = \frac{Re}{\delta^{1/2}} \tag{1}$$

Where, Re is the Reynolds number and δ is the curvature ratio of the bend [27].

One of the major recognition parameters of gas-solid flow is dimensionless Stocks number, that is a measure for deposition of aerosol particles in a bend and is defined as:

$$Stk = \frac{C\,\rho_p\,d_p^{\,2}\,U}{9\,\mu\,d_t} \tag{2}$$

Where C is the Cunningham's correction slip factor very close to unity for particles above 1 µm diameter; ρ_p, d_p and μ are the particle density, particle diameter and dynamic viscosity of fluid, respectively [20].

2. Governing Equations

2.1. Gas phase

The gas flow properties and turbulence quantities are calculated by solving a set of Reynolds averaged Navier-Stokes equations:

$$\frac{\partial\rho}{\partial t} + \nabla\cdot\left(\rho\bar{\vec{V}}\right) = 0$$

$$\frac{\partial}{\partial t}\left(\rho\bar{\vec{V}}\right) + \nabla.\left(\rho\overline{\vec{V}\vec{V}}\right) =$$

$$-\nabla\bar{P} + \nabla.\left[\mu(\nabla\bar{\vec{V}} + \nabla\bar{\vec{V}}^T)\right] + \frac{\partial}{\partial x_j}(-\rho\overline{V_i'V_j'}) \tag{3}$$

2.2. Particle Motion in Dispersed Phase

It is assumed that only drag and gravity forces are significant. Therefore, particle velocities and trajectories in bends are calculated by solving the equation of motion for particles in Lagrange frame simultaneously [10]:

$$\frac{du_{p,i}}{dt} = \frac{3\rho}{4\rho_p D_P} C_D\,(u_i - u_{p,i})\left|\vec{U} - \vec{U}_P\right| + g$$
$$\frac{dx_{p,i}}{dt} = u_{p,i} \tag{4}$$

Where U and U_P are local gas and particle instantaneous velocities, respectively.

u_i and $u_{P,i}$ are gas and particle velocity components as well as $x_{P,i}$ is the particle position coordinate.

The drag coefficient can be obtained by:

$$C_D = a_1 + \frac{a_2}{Re} + \frac{a_3}{Re^2} \tag{5}$$

In the above equation, a_1, a_2, and a_3 are constants which can be applied to spherical particles for a wide range of Re number. The relative Reynolds number can be defined by the following equation [20]:

$$\mathrm{Re} = \frac{\rho\, d_p \left|u - u_p\right|}{\mu} \tag{6}$$

In order to solve the equations of motion, i.e. Eq. (4), for each tracking particle in the flow domain, instantaneous fluid velocity components at all particle locations need to be determined. The inclusion of instantaneous fluid velocity components shows that the effects of turbulence are taken into account in calculating the particles motion. The present study adopts a classical stochastic approach for estimating the fluid fluctuating velocities.

3. Simulation of Flow Field

For calculating the three-dimensional flow field and particle tracking, the flow field is solved and subsequently a large number of particles are injected into it.

Turbulent flow is modeled by K-ε and Reynolds stress model (RSM) methods. The results of the K-ε solution are used as primary solution for RSM.

Since the Reynolds stress model includes the effects of streamline curvature and rotation in different curvatures, it can be used to illustrate the rotation of flow in a pipeline with asymmetric branches. In addition, this model can predict turbulent anisotropic stress in various points of knees [9, 11].

In all cases, velocity inlet and pressure outlet are utilized as boundary conditions. Velocity inlet changes for different cases while zero gauge pressure is imposed at the exit.

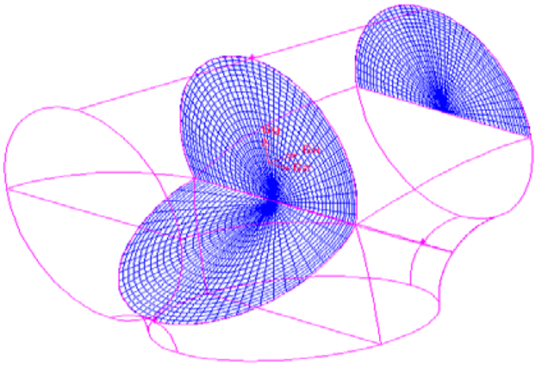
4. Particles Injection into the Flow Field

The injected particles velocity in the inlet is adjusted to the flow velocity [18]. The penetration of aerosol through bend and asymmetric branches of a pipeline is calculated by tracking a large number of particles released simultaneously. A plane is put in the inlet and particles are injected to flow by this plane. Particles are uniformly distributed over the face. It is worth mentioning that the rate of exit particles is independent of the number of particles injected by inlet plane. So, particles injection is done in any step with different particle number and this procedure is continued until the particles distribution in outlet becomes independent of the inlet particle number. The number of particles is 1500 for asymmetry pipeline. It can be shown that the rate of penetration in the pipeline does not change for a different number of injected particles. Since turbulent dispersion of particles is modeled by stochastic methods, particles injection is done several times for any inlet flow rate with a different particles size. Final results are obtained by averaging the data of each injection time.

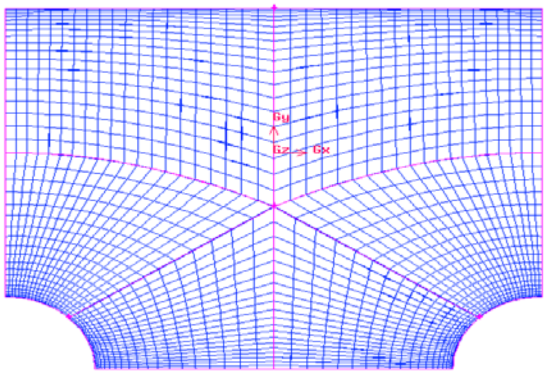
For a 90° pipe- knee, it is assumed that the wall is stick. Therefore, some of the particles can deposit in the knee according to the flow velocity. Thus, a trap boundary condition on the walls is used. But, for asymmetry pipeline, walls of the knee are dry and all exited particles are filtered. For this reason, the reflect boundary condition is used on pipe-knee walls. Outlet particle accumulation has been studied in order to determine the number and size of required filters in any outlet region.

5. Grid Generation

O topology is used for grid generating in the pipe and for T junction; grids are generated as shown in Figure 1. In order to have an accurate solution and modeling of the boundary layer, the grid must be fine in the vicinity of the walls. Figure 2 shows the representation of computational grid structures at pipe-knee junction and asymmetric branches in central gas station. Figures 2 and 3 show the representation of computational grid structures at pipe-knee junction and asymmetric branches in central gas station. In this study, the flow solution and particles injection are performed for 190,651 cells. About 76,000 of total cells are triangular and have been used in the pipe centerline whereas other ones are hexahedral elements.

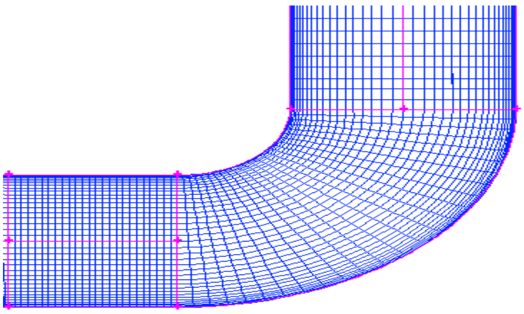


a) Three dimensional view T junction

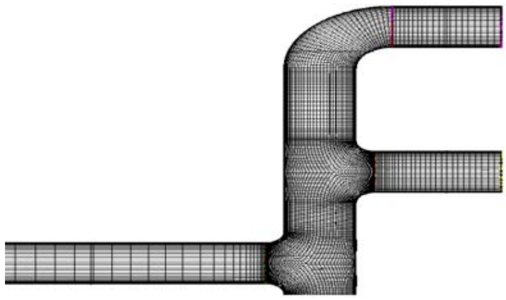


b) Two dimensional view T junction

Figure 1. The manner of grid generation at three ways



a) Pipe- knee junction



b) Three ways and asymmetric branches

Figure 2. The manner of grid generation

5.1. Grid Study for Main Geometry

Three grids with different cells have been generated for the main geometry in Figure 3. Table 1 shows no remarkable differences between velocity and pressure values in the first three ways for 135,667 and 190,6851 cells.

5.2. Study of Grid Quality with Focusing on Aspect Ratio

Table 2 shows the distribution percent of cells in four ranges of different aspect ratios. In all the knees, the three ways and the inlets, the amount of this parameter is in the range of 1-5. In the pipe which the flow is horizontal, less than twenty-five percent of cells, have aspect ratios higher than 15. In regions where the flow is in direction of axis coordinates, cells with partly high value of aspect ratio could not cause any significant problems in numerical solution and convergence trend.

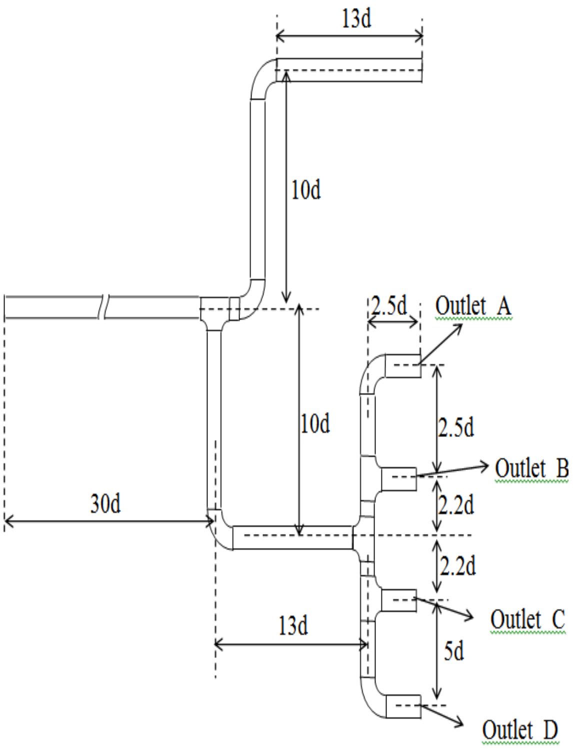


Figure 3. A Part of asymmetric branches in pipe line

Table1. Grid study for asymmetric branches shown in figure 3

Number of cells	Velocity at first three way	Pressure at first three way
828288	10.1147	6.8517
1356670	10.9124	7.2619
1906851	10.9213	7.2859

Table2. Grid Study of grid quality from Aspect ratio standpoint for Figure 3

Aspect ratio	Percentage of cells
$1 < Q_{AR} < 5$	50%
$5 < Q_{AR} < 10$	17%
$10 < Q_{AR} < 15$	11%
$Q_{AR} > 15$	22%

6. Results and Discussion

After grid study, three pipe-knees with different curvature ratio $R/a = 2,4,10$ have been analyzed (R and a are curvature radius of the bend and tube internal radius respectively. For all bends, the tube diameter is 16 mm. Velocity vectors in downstream of the bend exit plane and its symmetry are satisfied as shown in Figure 4. These results confirm the previous experimental study done by Mac Farland in 1997 [27].

The use of the (K-ε) model for the flow solution leads to a high difference in the percentage of particles penetration in comparison with experimental results which has been shown in Figure 5. Consequently, unlike RMS, this model cannot predict the particle behavior properly.

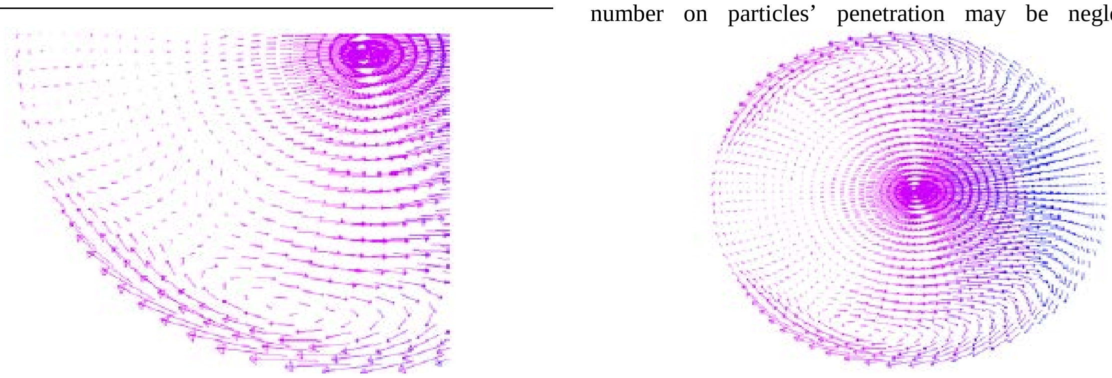
Figure 5 shows that, for three pipe-knees, particles penetration decreases with the increase of Stocks number. The Stocks number is varied by changing the flow rate through bend. With the increase of flow velocity, particles impact walls of pipe-knee with higher velocity when they want to change their path and travel with flow. Therefore, more particles are trapped in these regions.

6.1. Effect of Curvature Ratio on Particles Behavior

The effect of the curvature ratio on the behavior of particles in a 90^0 bend has been investigated. It is assumed that the stocks number is varied by changing the flow rate. As it is presented in Table 3, the particle penetration in bend is increased when the curvature ratio rises from 2 to 4, whereas when this increment continues from 4 to 10, the penetration of particles does not change considerably. This confirmed that increasing the bend curvature ratio can be recognized as an effective and reasonable method for augmenting transport particles. An increase in the curvature ratio from a certain bound, could lead to the waste of costs.

6.2. Effect of Reynolds Number on Particles Penetration in Bend

For considering the effect of Reynolds number on particles penetration, it is assumed that the Reynolds number varies while the Stokes number remains constant. The results are compared with experimental data and showed a reasonable agreement with what had been done by Mac Farland in 1997 [27]. Figure 6 demonstrates that by changing the Stokes number, particles' penetration does not change remarkably. Therefore, the effect of Reynolds number on particles' penetration may be neglected.



a) Velocity vectors in downstream of bend exit plane   b) Symmetry of velocity vectors in downstream of bend exit plane

Figure 4. The display of velocity vector

Table 3. Percentage of particles penetration versus Stocks number

Stocks number	**Percentage of particles penetration for** $R/a=2$	**Percentage of particles penetration for** $R/a=4$	**Percentage of particles penetration for** $R/a=10$
0.1	78%	88%	88.5%
0.15	70%	75%	77%
0.2	58%	68%	70%
0.25	49%	57%	57%
0.3	47.5%	55%	56%
0.35	38%	45%	46%
0.4	32%	39%	40%

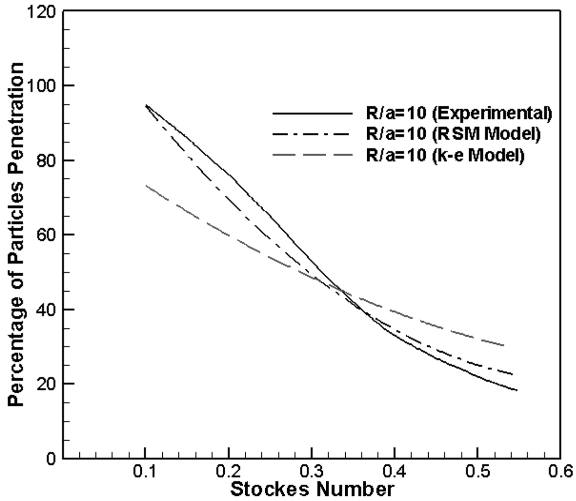


Figure 5. K-ε Model in comparison with RSM and experimental samples.

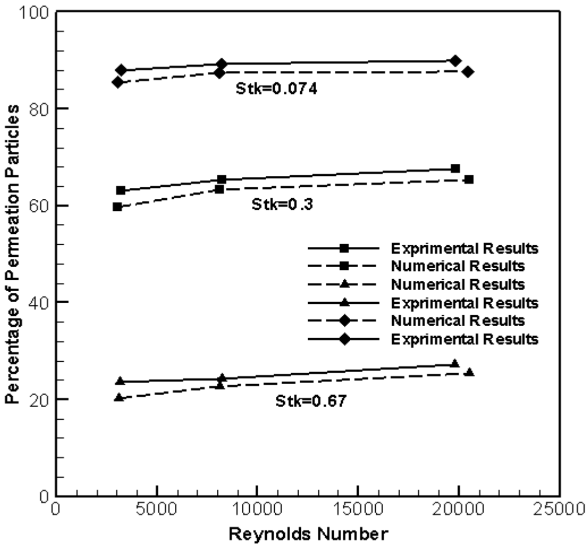


Figure 6. Percentage of particles penetration versus Reynolds number

7. Particles Distribution in Pipeline System with Asymmetric Branches

A part of asymmetric branches used in pressure reduction station is shown in Figure 3. For various inlet velocities, continuity and conservation of flow rate are conserved according to Table 4. Fluid in branches flows to the paths which cause fewer resistances against the flow. Therefore, it is expected that the most flow rate passes through the upper pipe. Velocity contour is shown in Figure 7.

The most flow rate passes through the upper part of the pipe. This is illustrated in Figure 7. Since particle does not affect the flow field and flow carries particles to the outlet, the most of accumulation particle in the outlet is in the upper part. This is shown in Table 5. Therefore, this region requires filters with higher quality and size to collect particles. Furthermore, the least number and smallest size are in *A* and D as shown in Figure 7.

For more investigation about the effect of asymmetry in branches, it is assumed that exit B in Figure 7 is blocked. In fact, flow geometry contains one inlet and three outlets A, C and D as shown in Figure 8. Results of particles injection into flow field have been shown in table 6. It could be concluded from Table 6 that the percentage of exit particles at outlet A increases to a nearly twice value, as compared with the cases in which there are four output regions at the lower part of the branch. This could be due to closing the B output region. Neither flow nor particles can exit through this outlet. Therefore, filters of higher quality and size are required at outlet A for collecting particles. Since flow tends to pass from shorter paths, the passing flow rate amount through the C region is higher than that of the D region. This fact is illustrated in Figure 7 which shows a velocity contour. C and D outputs are shown by $G-G$ and $F-F'$ cross sectional segments in Figure 7, respectively. Since flow propels particles to the outlet, it is expected that particles accumulation in C output region be more than D. Therefore, filters of higher quality and size are required for collecting particles at C output region in comparison with D, in Figure 7.

Table 4. Percentage of exit flow rate at outlet five-regions is shown in figure 3

Velocity inlet $(\frac{m}{s})$	Flow rate inlet $(\frac{kg}{s})$	Percentage of flow rate at upper pipe	Percentage of flow at A region	Percentage of flow at B region	Percentage of flow at C region	Percentage of flow at D region
4	0.63493	57.74	8.29	11.94	13.19	8.83
8	1.26987	57.48	8.9	12.1	12.91	8.6
12.3	1.95242	57.35	8.81	11.85	12.93	9.06

Table 5. Percentage of exit particles in five-outlet regions shown in figure 3

Velocity inlet $(\frac{m}{s})$	Diameter particle (μm)	Percentage of particles accumulation at upper pipe	Percentage of particles accumulation at A region	Percentage of particles accumulation at B region	Percentage of particles accumulation at C region	Percentage of particles accumulation at D region
4	10	56.8	9.5	11.7	11.1	10.9
8	10	56.1	10.1	12	10.7	10.1
12.3	10	56.1	10.8	11.7	11.6	10.8

Table 6. Percentage of exit particles with closing one of the outlets (B)

Percentage of exit flow at upper branch	Percentage of exit particles at upper branch	Percentage of exit flow at A region	Percentage of exit particles at A region	Percentage of exit flow at C region	Percentage of exit particles at C region	Percentage of exit flow at D region	Percentage of exit particles at D region
57.52	56.8	16.9	17.2	14.56	13.8	11.01	11.7

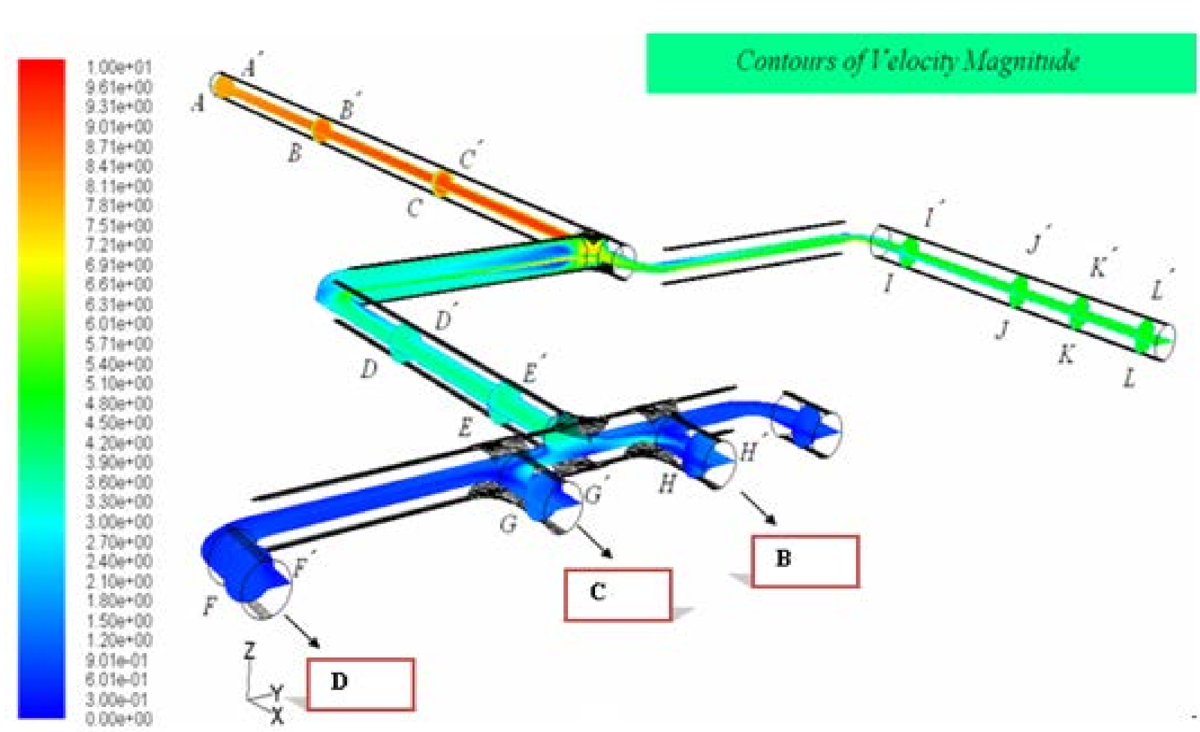


Figure 7. Velocity contour in pipe line with asymmetric branches

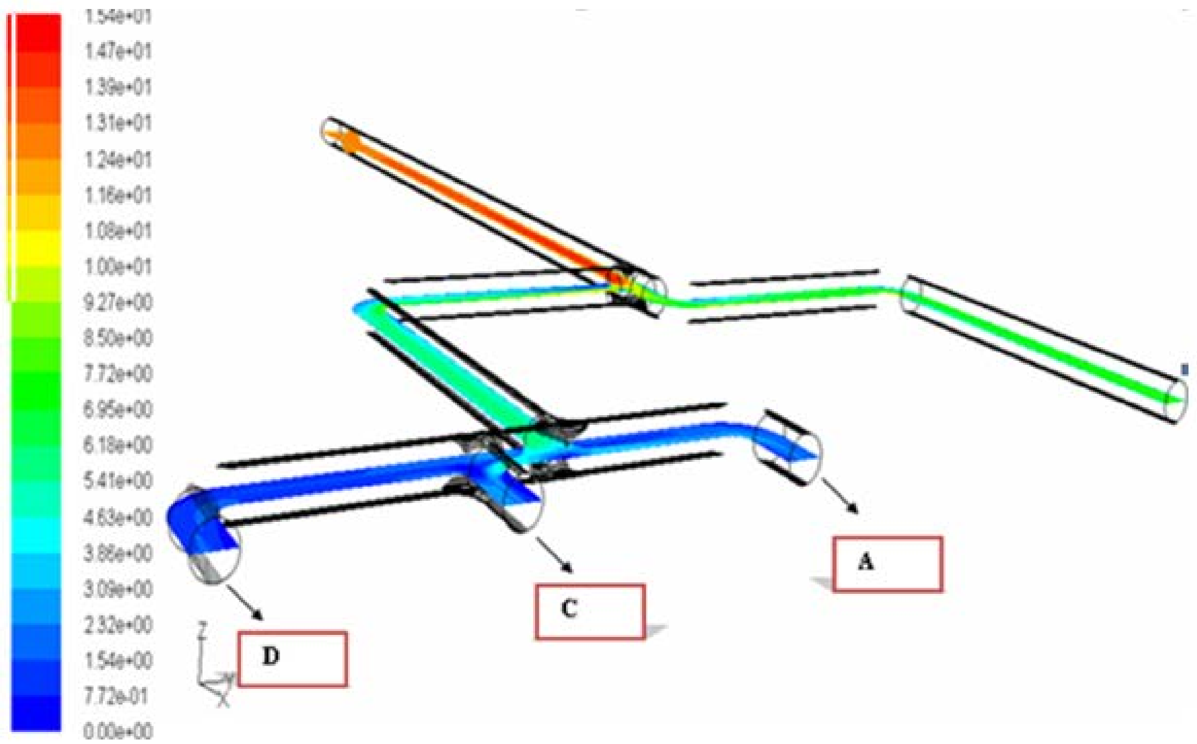


Figure 8. Velocity contour with closing one of the outlets (B)

Table 7. Percentage of exit particles with different boundary conditions at outlet

Percentage of exit particles at upper branch	**Percentage of exit particles at A region**	**Percentage of exit particles at B region**	**Percentage of exit particles at C region**	**Percentage of exit particles at D region**
45.2	7.9	19.5	19.8	7.2

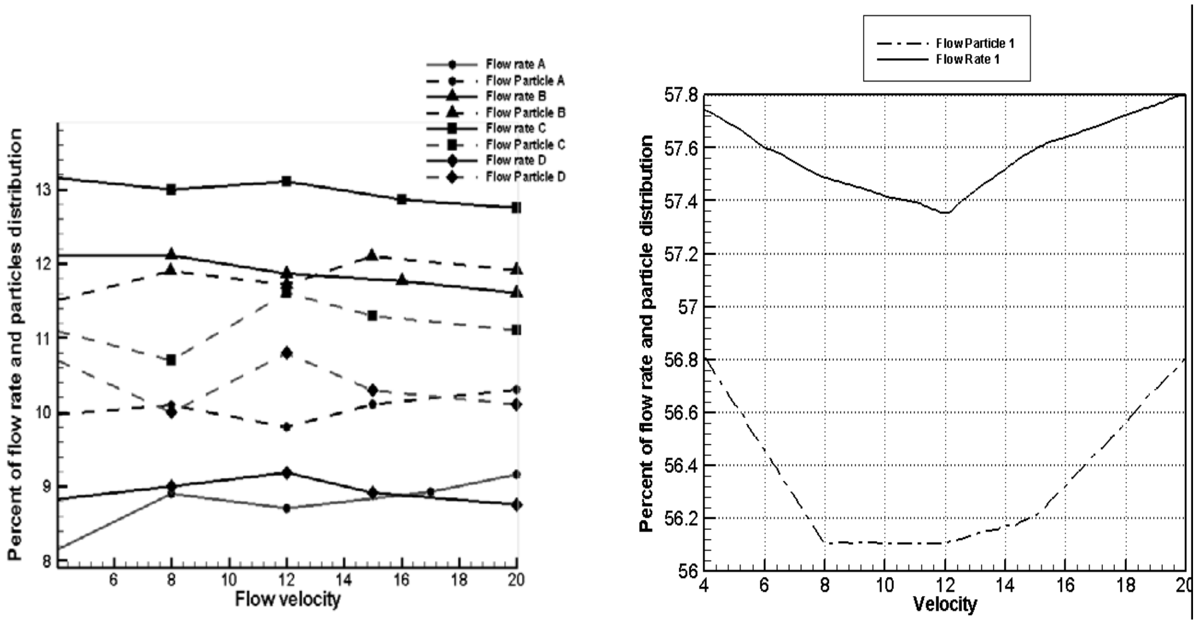
8. Effect of Pressure Variation on the Particles Distribution in Outlet

Different boundary conditions are considered at the outlets. In B and C, the value of pressure is set to *5.04 MPa* and in A and D *5.6 MPa* working pressure is exerted as boundary condition. Since the working pressure is supposed to be equal to atmospheric pressure, methane density should be calculated in *5.6 MPa* working pressure. Percentage of exit particles in various outlet regions for 12.3 m/s velocity inlet and 10-micrometer particle has been shown in Table 7.

Table 7 shows particles accumulation at the upper outlet as remarkable. In addition, due to the pressure reduction in B and C relative to A and D, the flow rate increases at B and C. Therefore, flow propels more particles to these regions. As a result, at B and C, under mentioned circumstances, filters of higher quality and size are needed.

9. Dependence of Flow Rate and Particles Distribution on the Fluid Velocity

The dependence of volume portion of particles and flow rate on fluid velocity is indicated in Figure 9. This also proved that this dependence increases at high flow velocities. This is mainly due to the drag force increment at higher velocities, which make it significantly larger than gravity force, whereas particle behavior is more unaffected by the flow in the velocities lower than 7 m/s. In figure 9, dependence of volume portion of particles at A, B, C and D regions has been shown with flow rate as well as dependency has been shown for upper part of pipe. In both of them, dependency is higher at high flow velocities because of increase drag force at higher flow velocities.



a) At A, B, C and D outlet regions

b) At upper exit region

Figure 9. Graphical relation particles distribution and flow rate

10. Effect of Particles Size upon Particles Distribution in Outlet

The form of particles distribution in the outlets is directly related to flow distribution at these regions. Therefore, for all injected particles with any diameter and size, it is expected that the amount of particles' accumulation at the upper exit region is more than that in other regions, while at A and D regions it is less than in other regions. Besides, flow tends to direct larger particles through simpler passage to exit regions. By increasing particles diameter, amount of particles' accumulation changes. Admittedly, the amount of particles accumulation reduces in the lower parts of branch and obviously increases in the upper exit region with the same amount. Since all the particles are in the size of micro and there is no remarkable difference in their size, particles distribution especially in the lower parts of branch is not considerable. Figure 10 shows the effect of particle size on the distribution of particle accumulation. More particles exit from the upper part and at the lower, a little difference is present between four branches.

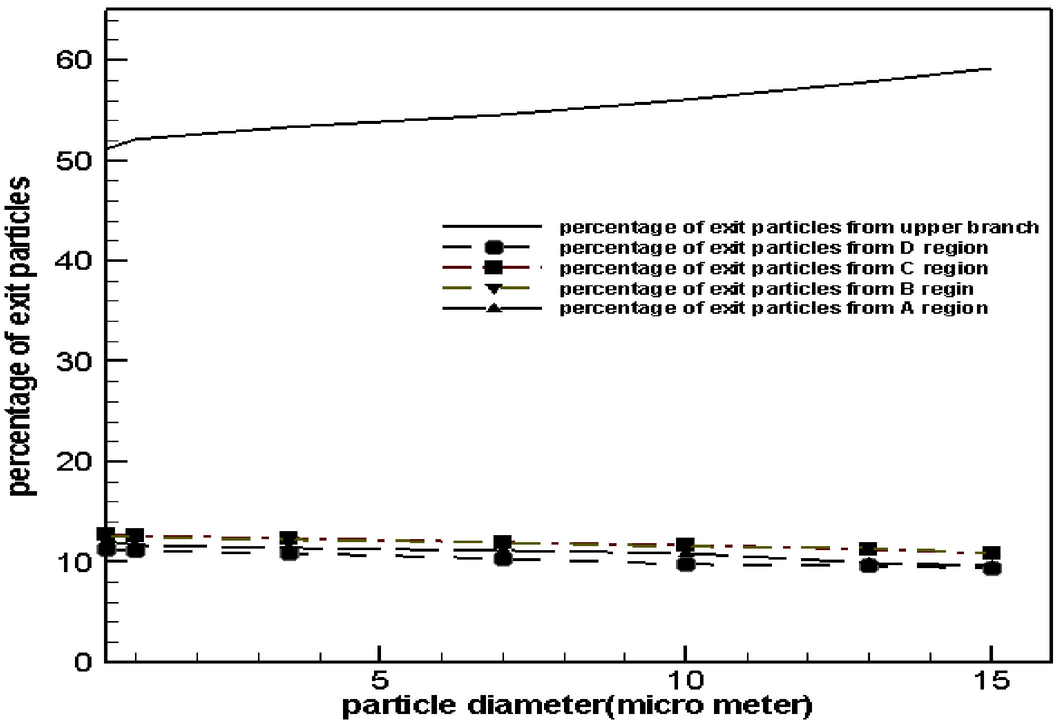


Figure 10. Particle distribution from exit regions versus particle diameter

11. Conclusions

Deposition of particles increases in the pipe-knee as the inlet flow velocity rises as opposed to the particles' behavior in the pipe without knee and branch. The increase in bend curvature ratio to a certain limit is relatively effective and plausible method for augmentation of transport particles. If curvature ratio exceeds from a certain ceiling, it leads to a waste of costs. It is worth noting that exit particles percentage is not found as a function of Reynolds number and it depends on the Stokes number only. Asymmetry in branches of piping systems has a very powerful effect on the distribution of particles. So, the required filters for trapping particles are dependent on the position of branches in these piping systems. In addition, at high flow velocities, particles behavior depends on flow pattern. This may be attributable to the significant increase in the drag force in comparison with gravity force.

References

[1] Cheng, Y.S., Wang, C.S.," Inertial deposition of particles in a bend". Journal of Aerosol Science, Volume 6, Issue 2, 1975, Pages139-145.

[2] Crane, RI., Evans, RL., "Inertial deposition of particles in a bent pipe". Journal of Aerosol Science, Volume 8, Issue 3, 1977, Pages161-170.

[3] Cheng Y.S., Wang, C.S., "Motion of particles in bends of circular pipes". Atmospheric Environment, Volume 15, Issue 3, 1981, Pages 301-306.

[4] Pui DYH, Romay-Novas, F., Liu BYH., "Experimental study of particle deposition in bends of circular cross section". Aerosol Sci Technol; Volume7, Issue 3, 1987, Pages 301–315.

[5] Tsai C.J., Pui DYH, "Numerical study of particle deposition in bends of a circular cross-section-laminar flow regime". Aerosol Sci Technol; Volume12, 1990, Pages 813–831.

[6] Ottjes, J. A., "Digital simulation of pneumatic particle transport". Chemical Engineering Journal, Volume 33, Issue 6, 1978, Pages 783-786.

[7] Tsuji, Y., Morikaw, Y., "Numerical simulation of gas-solid two-phase flow in a two-dimensional horizontal channel". International Journal of Multiphase Flow, Volume 13, Issue 5, 1987, Pages 671-684.

[8] Tsuji, Y., Shen, N., "Lagrangian simulation of dilute gas – solid flows in a horizontal pipe".Advanced Powder Technology, Volume 2, Issue1, 1991, Pages 63-81.

[9] Tashiro, H., Peng, X., Tomita,Y., "Numerical prediction of saltation velocity for gas-solid two-phase flow in a horizontal pipe". Powder Technology, Volume 91, Issue 2, 1997, Pages141-146.

[10] Hurber, N., Sommerfield, M., "Charactereization of the cross- sectional particle concentration distribution in pneumatic conveying systems". Powder Technology, Volume 79, Issue 3, 1994, Pages 191-210.

[11] Yilmaz, A., Levey, E. k., "Roping phenomena in pulverized coal conveying lines". Powder Technology, Volume 95, 1998, Pages 43-48.

[12] Lumley, J., "Two phase and non- Newtonian flows ", Turbulence, Topics in Applied Physics". Volume 12, 1978, Pages 289-324.

[13] Cox, R., Mason, S. "Suspended particles in fluid flow through tubes". Annual Review of Fluid Mechanics, Volume 3, 1971, Pages 291-316.

[14] Yianneskis, M., Whitelaw, J., "Velocity characteristics of pipe and jet flows with high particle concentrations". Fluids Sec., Mechanical Engineering Department, Imperical College of Science and Thechnology, 1983.

[15] Hajji,L., Pascal,Ph., Oesterel,B., " A simple description of some inertia effects in the behaviour of heavy particles in a turbulent gas flow".International Journal of Non-Linear Mechanics, Volume31, Issue 3, 1996, Pages387-403.

[16] Hurber, N., Sommerfield, M., "Modeling and calculation of dilute – phase pneumatic conveying in pipe systems". Powder Technology, Volume 99, Issue 1, 1998, Pages 90-101.

[17] Sommerfeled, M., Lain, S., Kussin, J., "Analysis of transport effects of turbulent gas - particle flow in a horizontal channel". The Fourth International Conference on Multiphase Flow, ICMF, 2001.

[18] Kuan, B., Schwarz, M., "Numerical prediction of dilute particulate flows in horizontal and vertical ducts". Proceedings of the Third International Conference on CFD in the Minerals and Process Industries CSIRO, Australia, 2003, Pages 135-140.

[19] Kuan, B. T., "CFD simulation of dilute gas – solid flows with different solid size distribution in a curved 90˚ duct bend". Journal of ANZIAM.,Volume 46, 2005, pages 44-763.

[20] Dehbi, A., "A CFD model for particle dispersion in turbulent boundary layer flows". Journal of Nuclear Engineering and Design, Volume 238, Issue 3, 2008, pages 707-715.

[21] Hadinoto, Kunn., Curits, Jennifer. " Reynolds number dependence of gas-phase turbulence in particle-laden flows". Powder Technology, Volume 195, 2009, Pages 119-127.

[22] Mando,M., Lightstone, M.F., Rosendahl, C. " Turbulence modulation in dilute particle-laden flow". International Journal of Heat and Flluid Flow". Volume 30, Issue 2, 2009, Pages 331-338.

[23] Ono, A., Kimura, N., Kamide, H., Tobita,A. " Influence of elbow curvature on flow structure at elbow outlet under high Reynolds number condition". Nuclear Engineering and Design, Volume 241, Issue 11, 2011, Pages 4409-4419.

[24] Lain, Santiago., Sommerfeld,Martin. "Numerical calculation of pneumatic conveying in horizontal channels and pipes". International Journal of Multiphase Flow, Volume 39, 2012, Pages 105-120.

[25] Founti, M., Klipfel, A. "Experimental and computational investigation of nearly dense two-phase sudden expansion flows". Experimental Thermal and Fluiid Science, Volume 17, Issue 1-2, 1998, Pages 27-36.

[26] Taylor, G. "diffusion by continuous movements" proc. of the London Mathematical Society, Volume 20, 1921, Pages 193-212.

[27] McFarland, A. R., Gong, H., "Aerosol deposition in bends with turbulent flow". Environ. Sci. Technol., Volume 31, 1997, Pages 3371-3377.

JJMIE

Volume 8 Number 2, April. 2014
ISSN 1995-6665
Pages 66 - 74

Jordan Journal of Mechanical and Industrial Engineering

Reduced Chemical Kinetic Mechanisms: Simulation of Turbulent Non-Premixed CH_4-Air Flame

Guessab Ahmed [a] *, Aris Abdelkader [b], Abdelhamid Bounif [c], Iskander Gökalp [d]

[a] *Laboratorie de l'Innovation des Produits et Systèmes Industriels (IPSILab), Département de Génie Mécanique, ENP d'Oran, Oran 31000*

[b,c] *Laboratoire des Carburants Gazeux et Environnement, Département de Mécanique,USTOMB d' Oran, Oran 31000.*

[d] *Laboratoire de Combustions et Système Réactifs, CNRS, 45071 Orléans, France.*

Abstract

Natural gas is the primary fuel for industrial gas turbines. Although natural gas is mostly Methane, its composition varies. The size of the detailed chemical kinetic model is too large to be used in CFD-Fluent code. The aim of this study is to reduce the number of species and reactions to get a mechanism small enough to use in Fluent. An 8-species reduced mechanism was successfully implanted into the Fluent.

Keywords: *Natural-Gas, Chemical Reactions, EDC, CFD-Fluent .*

1. Introduction

Combustion plays an important role in many industrial applications because it is the main source of producing power and energy. Also, from an environmental point of view, emission of pollutants, due to combustion, causes significant health problems. Therefore, the study of combustion is an important issue for many investigators. Since experimental investigation of combustion is expensive, numerical simulation has been used for decades. Numerical methods have become powerful tools to simulate complex combustion processes and to understand the physics involved. For simulation of combustion, Arrhenius model, the eddy-dissipation concept models are widely used in CFD. One of the most practical models is the eddy-dissipation concept model because it is easy to implement and its results are acceptable for premixed and non-premixed flames. In the eddy-dissipation concept model, every reaction is the same and the model takes into account the turbulent rate only. Therefore, the model should be used only for one-step global reaction and it cannot predict radical species. Multi-step chemical mechanisms are based on Arrhenius rates, and the Arrhenius model computes the rate of reaction using Arrhenius expressions. The Arrhenius model is exact for laminar flames, but is inaccurate for turbulent flames, because this model ignores turbulent fluctuations that are effective on the rate of reaction, temperature, and concentration of pollutants.

Oxidation of methane is perhaps the most important combustion reaction because the main component of natural gas is methane and its combustion is of great economical importance. Several reaction mechanisms have been developed for the description of methane combustion. The combustion is now one of the major processes to produce energy, whether it is starting from coal, oil or gas. Methane is the simplest hydrocarbon fuel available; several studies have focused on Methane/Air flames. The oxidation of methane is quite well understood and various detailed reaction mechanisms are reported in literature [1;2]. They can be divided into full mechanisms, skeletal mechanisms, and reduced mechanisms. The various mechanisms differ with respect to the considered species and reactions. However, considering the uncertainties and simplifications included in a turbulent flame calculation, the various mechanisms agree reasonably well [3].

In literature, several mechanisms of methane combustion exist. We can cite, for detailed mechanisms: Westbrook [4], Glarborg *et al*. [5], Miller and Bowman [6], and, recently, Konnov v.0.5 [7], Huges *et al*. [8], LCSR [9], Leeds v.1.5 [10], San Diego [11] and the standard GRI-Mech v.3.0 and GRI-Mech v.1.2 [12]; for reduced mechanisms: Westbrook and Dryer [13], and Jones and Lindstedt [14] (more than 2 global reaction); for skeletal mechanisms: Kazakov and Frenklach [15], Yungster and Rabinowitz [16], Petersen and Hanson [17], Hyer *et al*. [18] and Li and Williams [19].

The need to use reduction techniques detailed mechanisms to reduce the computation time and memory allocated by reducing the number of species by reducing the stiffness of the system of differential equations while retaining some predictive qualities of the mechanism. It involves identifying and eliminating non-first important species and then significant reactions. Several studies have focused on the turbulent combustion: M. Cannon *et al*.

[20] numerically studied a diffusion flame of methane with a reaction mechanism reduced from five elementary reactions, deducted from GRI-Mech 2.11 [12]. M. Jazbec *et al*. [21] conducted a numerical study based on a new model developed for the hydrodynamic chemical reaction mechanism with 16 species and 28 reactions. The effectiveness reduced in combustion mechanisms is also emphasized by A. L. Sanchez *et al*. [22].

The present work is focused on the simulation of turbulent confined non-premixed flame of Natural gas. The reduced chemical kinetics scheme of Hyer was used to describe the combustion process in terms of eight chemical reaction equation and 8 species (CH_4, H_2, CO, CO_2, H_2O, O_2, C_2H_6 and N_2), using the commercial code CFD fluent v6. Some modifications of the usually adopted models for the representation of the turbulence-kinetics interaction are introduced.

2. Problem Description

The numerical model proposed for this study is based on the geometry and dimensions of the experimental jet in co-flow burner used by Lewis and Smoot [23]. The experimental burner geometry for this test is a cylindrical combustor with coaxial injectors, where the primary tube and the air through the secondary annulus inject the natural gas. The total pressure of the combustor is 94 KPa. In the fuel stream, the uniform inlet gas velocity is 21.3 m/s and the mass flow rate is 2.982 g/s, with a temperature of 300 K. Table 1 lists the experimental conditions. The fuel jet consists of 71.8% CH_4, 11.4% C_2H_6, 3.6% N_2, 3 % CO_2, 0.2% H_2 and 10% Ar. In the air stream, the uniform inlet air velocity is 29.9 m/s and the mass flow rate is 36.3 g/s, with a preheated temperature of 589 K. The average Reynolds number at the chamber inlet results in 17900. Due to the symmetry of the burner, a geometrically simplified axisymmetric computational model was constructed to simulate the burner. The computational domain started at the exit plane of the burner, and extended 1.525m downstream across the axial direction and 10.16cm across the radial direction. The equivalent axisymmetric constructed computational model is shown in Figure 1.

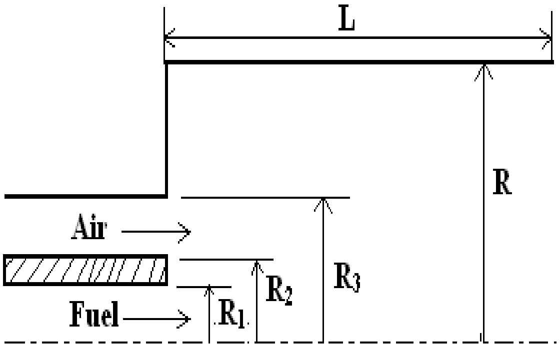


Figure 1. Sketch of the computational domain [23].
(R_1=0.8cm, R_2=1.11cm, R_3=2.86cm, R= 10.16 cm, L=1.525m)

3. Numerical Modeling

3.1. Government Equations

Balance equations for the mean quantities in RANS simulations are obtained by averaging the instantaneous governing equations. This averaging procedure introduces unclosed quantities that have to be modeled by using turbulent combustion models. Using the Favre averages formalism, the averaged balance equations become [24]:

$$\frac{\partial}{\partial x_i}(\bar{\rho}\tilde{u}_i) = 0 \quad (1)$$

$$\frac{\partial}{\partial x_i}\left(\bar{\rho}\tilde{u}_i\tilde{u}_j\right) + \frac{\partial \bar{p}}{\partial x_j} = \frac{\partial}{\partial x_i}\left(\bar{\tau}_{ij} - \bar{\rho}\,\overline{u_i'' u_j''}\right) \quad (2)$$

$$\frac{\partial}{\partial x_i}\left(\bar{\rho}\tilde{u}_i\tilde{Y}_k\right) = \frac{\partial}{\partial x_i}\left(\left(\frac{\mu}{Sc_k} + \frac{\mu_t}{Sc_t}\right)\frac{\partial \tilde{Y}_k}{\partial x_j} + \bar{\rho}D_k\frac{\partial \tilde{Y}_k''}{\partial x_j}\right) + \bar{R}_i \quad (3)$$

$$\frac{\partial}{\partial x_i}\left(\bar{\rho}\tilde{u}_i\tilde{h}\right) = \frac{\overline{DP}}{Dt} + \frac{\partial}{\partial x_i}\left(\frac{\mu}{\mathrm{Pr}}\frac{\partial \tilde{h}}{\partial x_i} - \bar{\rho}\,\overline{u''_i\,h''}\right) \quad (4)$$

In Eq. 3, the thermal diffusion (Soret effect) and the pressure diffusion are neglected. In this work it is assumed that S_{ck} (Schmidt number) is unity which means that the effective specie diffusivity is equal to the viscosity.

3.2. 3.2. Turbulence Modeling

The standard (k-ε) model (including a correction for round jets performed by using the Pope formulation) turbulence closure model is adopted. In the k-ε model, the Reynolds stress is closed using mean velocity gradients employing Boussinesq hypothesis. The Reynolds stresses tensor:

$$\overline{\rho u''_i\,u''_j} = \frac{2}{3}\bar{\rho}k\delta_{ij} - \mu_t\left(\frac{\partial \tilde{u}_i}{\partial x_j} + \frac{\partial \tilde{u}_j}{\partial x_i} - \frac{2}{3}\delta_{ij}\frac{\partial \tilde{u}_k}{\partial x_k}\right) \quad (5)$$

The turbulent fluxes of species and enthalpy can be closed with a gradient-diffusion hypothesis with the relations:

$$\overline{\rho u_i'' Y_k''} = -\frac{\mu_t}{Sc_{t,k}}\frac{\partial \tilde{Y}_k}{\partial x_i} \quad (6)$$

$$\overline{\rho u_i'' h_s''} = -\frac{\mu_t}{\mathrm{Pr}_t}\frac{\partial \tilde{h}_i}{\partial x_i} \quad (7)$$

Where, $S_{ct,k}$, and Pr_t are the turbulent Schmidt number and the turbulent Prandtl number, accordingly. Jones and Launder (1972) [25] devised the standard k-ε model, in which they define the turbulent kinematic viscosity as well as the transport equations for turbulent kinetic energy and turbulent kinetic energy dissipation rate, ε:

$$\mu_t = C_\mu \bar{\rho}\frac{\tilde{k}}{\varepsilon_t}$$

(8)

$$\frac{\partial}{\partial x_i}\left(\bar{\rho}\tilde{u}_i k\right) = \frac{\partial}{\partial x_i}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_i}\right] + P_k + G - \bar{\rho}\varepsilon \quad (9)$$

$$\frac{\partial}{\partial x_i}(\bar{\rho}\tilde{u}_i\varepsilon)=$$

$$\frac{\partial}{\partial x_i}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_i}\right]+C_{\varepsilon 1}\frac{\varepsilon}{k}\left(P+C_{\varepsilon 3}G\right)-C_{\varepsilon 2}\bar{\rho}\frac{\varepsilon^2}{k}+P_{PC} \quad (10)$$

Where G is the turbulent kinetic energy production terms due to buoyancy effect, which are neglected in the present numerical model. The turbulent energy production tensor due the mean velocity gradients, P_k, is given by

$$P_k = -\overline{u_i^{"} u_j^{"}}\frac{\partial \tilde{u}_i}{\partial x_j} \quad (11)$$

In the case of a jet flame, a correction is necessary to accurately predict the spreading rate of the jet. This is performed by using the Pope correction, P_{pc}, as an additional term in the equation of turbulence dissipation rate (ε):

$$P_{PC} = \bar{\rho} C_{\varepsilon 3}\frac{\varepsilon^2}{k} S_\varepsilon \quad (12)$$

The term Sε can be written as (Pope, 1978) [23]:

$$S_\varepsilon = \omega_{ij}\omega_{jk}S_{ij} \quad (13)$$

Where:

$$S_{ij} = \frac{1}{2}\frac{k}{\varepsilon}\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right) \quad (14)$$

$$\omega_{ij} = \frac{1}{2}\frac{k}{\varepsilon}\left(\frac{\partial u_i}{\partial x_j}-\frac{\partial u_j}{\partial x_i}\right) \quad (15)$$

Where: $C_{\varepsilon 3} = 0.79$.

The standard values for the model constants (Launder and Sharma (1974) have been chosen) are:

$C_\mu = 0.09$, $C_{\varepsilon 1} = 1.44$, $C_{\varepsilon 2} = 1.92$, $\sigma_k = 1.0$, $\sigma_\varepsilon = 1.3$

4. Turbulence Combustion Interaction

4.1. Eddy Dissipation Concept (EDC)

The description of the turbulence-chemistry interactions represents one of the most difficult tasks in turbulent combustion; it is necessary to adopt a robust model that accounts for both the chemistry and the turbulence such as the EDC model. Not to be confused with the well known Eddy Dissipation model [26], the eddy-dissipation-concept (EDC) model is an extension of the eddy-dissipation model to include detailed chemical mechanisms in turbulent flows. It assumes that the reaction occurs in small turbulent structures, called the fine scales. The length fraction of the fine scales, γ is modeled as:

$$\gamma = 2.1377\left(\frac{\nu\varepsilon}{k^2}\right)^{1/4} \infty \mathrm{Re}_t^{-1/4} \quad (16)$$

Where, the volume fraction constant = 2.1377, and ν is the kinematic viscosity. Species are assumed to react in the fine structures over a time scale τ, which is proportional to the kolmogorov time scale:

$$\tau = 0.4082\sqrt{\frac{\nu}{\varepsilon}} \infty t_{Kolmogorov} \quad (17)$$

The time scale constant is equal to 0.4082. This constant can be adjusted in FLUENT either to accelerate or slow down the reaction. Decreasing the time scale constant will result in an acceleration of the reaction while increasing it slows down the reaction process. FLUENT assumes that the combustion at the fine scales proceeds as a constant pressure reactor, where * denotes fine-scale quantities:

$$\frac{dY_k^\bullet}{dt} = \frac{\varpi_k}{\rho^\bullet} \quad (18)$$

With the initial conditions taken as the current species and temperatures in the cell. Initial condition:

$Y_k^* = Y_k$. Y_k^* is the fine scale species mass fraction after reacting over time τ. The source term Sk in the general conservation equation for the mean species i is modeled as:

$$S_K = \frac{\gamma^2}{\tau}\left(Y_k^\bullet - Y_k\right) \quad (19)$$

4.2. Chemical Reaction Mechanism for Natural Gas

In this study, the Hyer mechanism often used in combustion modeling of natural gas (Table 1), is an eight-step reaction for reversible.

Table 1. Hyer chemical kinetics mechanism and Arrhenius rate coefficients [18].

Reaction	A_k	E_k [*j/Kmol*]	β_k
$CH_4+0.5O_2 \rightarrow CO+2H_2$	4.40e+09	1.26e+08	0
$CH_4+H_2O \rightarrow CO+3H_2$	3.00e+08	1.26e+08	0
$CO+H_2O \rightarrow CO_2+H_2$	2.75e+10	8.37e+07	0
$CO_2+H_2 \rightarrow CO+H_2O$	9.62e+10	1.26e+08	-0.85
$H_2+0.5O_2 \rightarrow H_2O$	7.45e+13	1.67e+08	-0.91
$H_2O \rightarrow H_2+0.5O_2$	3.83e+14	4.12e+08	-1.05
$C_2H_6+O_2 \rightarrow 2CO+3H_2$	4.20e+11	1.25e+08	0
$C_2H_6+2H_2O \rightarrow 2CO+5H_2$	3.00e+08	1.25e+08	0

In general, a chemical reaction can be written in the form as follows:

$$\sum_{i=1}^{N} \upsilon'_{i,k} A_i \Leftrightarrow \sum_{i'=1}^{N} \upsilon''_{i,k} A_i \quad (20)$$

Where:

N = number of chemical species in the system

$\upsilon'_{i',k}$ = Stoichiometric coefficient for reactant i in reaction k

$\upsilon''_{i',k}$ = Stoichiometric coefficient for product i in reaction k

A_i = chemical symbol denoting species i

$k_{f,k}$ = forward rate constant for reaction k

$k_{b,k}$ = backward rate constant for reaction k

Equation 3 is valid for both reversible and non-reversible reactions. For non-reversible reactions, the backward rate constant kb,k is simply omitted. The summations in Eq. 17 are for all chemical species in the system, but only species involved as reactants or products will have non-zero stoichiometric coefficients, species that are not involved will drop of the equation except for third-body reaction species. The mole reaction rate, $\hat{R}_{i',k}$ [$Kmol.m^{-3}.s^{-1}$] is determined from Eq. 18.

$$\hat{R}_{i',k} = \frac{d\lfloor C_j \rfloor}{dt} \Gamma\left(\upsilon''_{i,k} - \upsilon'_{,k}\right) \left(k_{f,k} \prod_{j=1}^{N} [C_j]^{\eta'_{j,k}} - k_{b,k} \prod_{j=1}^{N} [C_j]^{\eta''_{j,k}}\right) \quad (21)$$

Where $\lfloor C_j \rfloor$ $\left[\frac{Kmol}{m3}\right]$ is the mole concentration of species *j* in reaction *k*, $\upsilon'_{,k}$ and $\upsilon''_{i,k}$ are the reactant and product stoichiometric coefficients of species *i* in reaction *k* , respectively,

$\eta'_{j,k}$ and η''_{jk} are the rate exponents of the reactant and product *j'* in reaction *k* , respectively, Γ is the net effect of third bodies on the reaction rate. This term is given by:

$$\Gamma = \sum_{j'}^{N} \gamma_{j,k} C_j \quad (22)$$

Where $\gamma_{j'k}$ is the third-body efficiency of the $j'th$ species in the k_{th} reaction. The forward and backward reaction rate constants $k_{f,k}$ and $k_{b,k}$ are usually evaluated with the Arrhenius equation given in Eq. 20.

$$k_{f,k} = A_k T^{\beta_k} \exp\left(-E_k/RT\right) \quad (23)$$

Where A_k is the pre-exponential constant of reaction *k*, T [K] is the temperature, β_k *is* the temperature exponent of reaction *k*, E_k [$J.Koml^{-1}$] is the activation energy of reaction *k* and *R* [$J.Kmol^{-1}.K^{-1}$] is the gas constant. The values of $\upsilon'_{i,k}, \upsilon''_{,k}, \eta'_{,k}, \eta''_{i,k}, \beta_k, A_k, E_k$ and $\gamma_{j'k}$ can be provided the problem definition. The mass reaction rate of species *j* in reaction *k*, $R_{j,k}$ [$Kg.m^{-3}.s^{-1}$] is determined with Eq. 21:

$$R_{j,k} = \overline{R}_{j,k} M_j \quad (24)$$

If the reaction is reversible, the backward rate constant for reaction *k* using Eq. 22. Unless a distinct reverse reaction is specified. Determination of K_k is discussed by:

$$k_{b,k} = \frac{k_{f,k}}{K_k} \quad (25)$$

Where k_k is the equilibrium constant for the *k*-th reaction. Computed from:

$$K_k = \exp\left(\frac{\Delta S_k^0}{R} - \frac{\Delta H_k^0}{RT}\right)\left(\frac{P_{atm}}{RT}\right)^{\sum_{k=1}^{NR}\left(\upsilon''_{i,k} - \upsilon'_{i,k}\right)} \quad (26)$$

Where P_{atm} denotes atmospheric pressure (101325Pa). The term within the exponential represents the change in Gibbs free energy, and its components are computed as follows:

$$\frac{\Delta S_k{}^\circ}{R} = \sum_{i'=1}^{N}\left(\upsilon''_{i,k} - \upsilon'_{i,k}\right)\frac{S_i^0}{R} \quad (27)$$

$$\frac{\Delta H_k^0}{RT} = \sum_{i'=1}^{N}\left(\upsilon''_{i,k} - \upsilon'_{i,k}\right)\frac{h_i^0}{R} \quad (28)$$

Where $S_{i'}^0$ and $h_{i'}^0$ are, respectively, the standard-state entropy and standard-state enthalpy including heat of formation. FLUENT employs the SI unit system. The values given in Table 5 and 6 are given in the units [cm], [s], [cal] and [mol] must therefore be converted.

5. Simulation Details

The numerical simulation of the flow field includes the solution of the governing equations which consists of Favre-averaged form of continuity, momentum, energy, species conservation, and modified standard k-ε equations. It consists of 8 species and 8 reversible reactions. The standard k-ε turbulence closure model is adopted. The governing equations are solved using the Fluent CFD package modified with User Defined Functions (UDF) in order to integrate the reaction rate formula proposed by Hyer [18]. In Fluent, the differential equations governing the problem are discretized into finite volume and then solved using algebraic approximations of differential equations. SIPMLE algorithm was chosen for the coupling between the velocity and the pressure. For all simulations presented in this paper, a First Order Upwind Scheme was used for the conservation equation of momentum, turbulent kinetic energy, turbulent dissipation rate, mean mixture fraction. The Standard scheme was used for interpolation methods of pressure. This means that the solution approximation in each finite volume was assumed to be linear. This saved computational expenses. In order to properly justify using a first order scheme, it was necessary to show that the grid used in this work had adequate resolution to accurately capture the physics occurring within the domain. In other words, the results needed to be independent of the grid resolution. This was verified by running simulations with higher resolution grids. In a reacting flow, such as that studied in this work, there are significant time scale differences between the general flow characteristics and the chemical reactions. The criterion of convergence is the summation of residual mass sources less than 10^{-3} for the other terms of the transport equations and is 10^{-6} for energy equation. The computational space seen in Figure 1 given a finite volume mesh is divided by a staggered non-uniform quadrilateral cell (Figure 2). A total number of 5600 quadrilateral cells were generated using non-uniform grid spacing to provide an adequate resolution near the jet axis and close to the burner where gradients were large. The grid spacing increased in radial and axial directions since gradients were small in the far-field. The combustion will be modeled using a reduced 8-step reaction mechanism scheme, and the radiative heat transfer of the diffusion flame is calculated with the *P1* model [24]. The density is obtained from the ideal gas law. The interaction between turbulence and chemistry is often handled through the

Eddy-Dissipation Concept (EDC). The controlling rate is assumed to be the slower between the kinetic values and turbulent mixing rate. The specific heat values for the species are defined as piecewise-polynominal function of temperature. The options used in this work are presented in Tables 2 and 3:

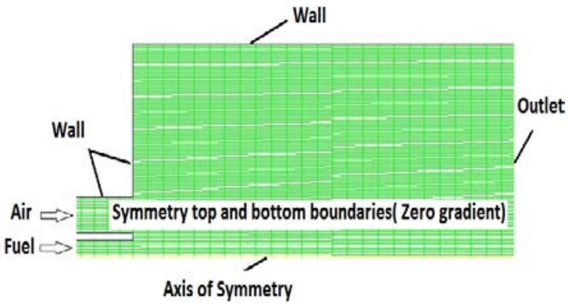


Figure 2. 2D view of the computational domain (Mesh) and boundary conditions.

Table 2. Under-Relaxation factors

Pressure	0.3
Density	0.5
Body Forces	1
Momentum	0.7
Turbulent Viscosity	0.9
Species Concentration Y_i	0.9
Energy E	0.4
Turbulent kinetic energy 'k'	0.8
Turbulent dissipation rate 'ε'	0.8

Table 3. Discretization and computational model step.

Solver Type	Pressure Based
Viscous Model	Turbulent (k-ε)
2D-Space	Axisymmetric
Pressure-Velocity Coupling	SIMPLE
Pressure	Standard
Momentum Equations	First Order Upwind
Species Equations	First Order Upwind
Energy Equation	First Order Upwind
Turbulent kinetic Energy	First Order Upwind
Turbulent Dissipation Rate	First Order Upwind

6. Results and Discussions

In this section, we present simulation results and we compare them with the experimental data. In this study, we discuss predictions of the mass fraction of all species. Finally, we analyze the predictions of mean temperature. The sensitivity of the predictions to the choice of k-ε model ($C_{\varepsilon 3}$ = 0.79), chemical kinetic mechanism and the EDC model for turbulence-chemistry interaction is studied. The reduced mechanism of Hyer was previously validated on the basis of non-premixed flames. Then, the mechanism implemented into the CFD code Fluent, using the method of directed relation graph and Quasi Steady State Assumption. The mechanism was incorporated into the Fluent by the means of a user-defined function that uses the subroutine (Define-Net-Reaction-Rates) to compute the species reaction rates, which are fed into the turbulence-combustion model. The FORTRAN subroutine is linked to Fluent through the (DNRR) argument macro. This macro is called the EDC model and used to compute the closed turbulent species reaction rates. The EDC uses the FORTRAN reactions rates as an input to the turbulent reaction rates. In this manner, the UDF is a complement to the EDC model and does not by-pass the EDC model. Once the reduced mechanism is constructed and executed, the subroutine that computes the chemical source terms is automatically generated. A coupled set of nonlinear Quasi Steady State species equations are numerically solved within the subroutine to provide the necessary elementary reaction rates for the reduced mechanism. This subroutine, which is compatible with FLUENT, is specified in the user-defined function and returns the molar production rates of the species given the pressure, temperature, and mass fractions. The Under-relaxation factors are different for different variables, varying from 0.3 to 0.9. The energy equation is very difficult to converge, so the factor is taken as 0.4. The inlet turbulent specification method is 'intensity and length scale'. Turbulence intensity is 10% and turbulence length scales are 0.008 m for fuel and 0.0175 m for air. We begin by comparing the computational cost of Hyer mechanism and the global mechanism model [13], in terms of the average CPU (execution) time per time step. The relative elapsed CPU times are compared in Table 4.

Table 4. Average execution time per time step.

Kinetic model	Species	Reaction	CPU [s]	Iter.
1-step	04	01	0.00596	1635
8-step	08	08	0.0854	15356

In the 8-step mechanism, more reaction equations are computed, then more CPU time is spent and it becomes more difficult to converge. In general, the computational cost increases with the number of reaction-step and species and it becomes more difficult for convergence. Figures 4 and 5 show the contour plot of the temperature fields from the simulation using the Global and Hyer mechanisms.

It is noticed that the smallest flame is predicted by the 1-step scheme, whereas the largest flame is predicted by the 8-step model. It is observed that the predicted maximum temperature calculated for the turbulent diffusion flame, using different chemical kinetic schemes for 1-step model, is 2960 K, but in the 8-step scheme, it is 2680 K. The 1-step mechanism assumes that the reaction products are CO_2 and H_2O, the total heat of reaction is over predicted.

In the actual situation, some CO, C_2H_6 and H_2 exist in the combustion products with CO_2 and H_2O. This lowers the total heat of reaction and decreases the flame temperature. The 8-step mechanism includes CO, C_2H_6 and H_2, so we can get more detailed chemical species distribution.

Radial composition profiles for CH_4, CO_2, O_2, H_2O, CO, H_2, C_2H_6 and Temperature (K) at several axial locations (x = 10, 25 and 50 cm) are shown in Figures 5 to 11, and the test results of Lewis and Smoot are also shown. Those figures show that the calculated results are in good agreement with experimental data.

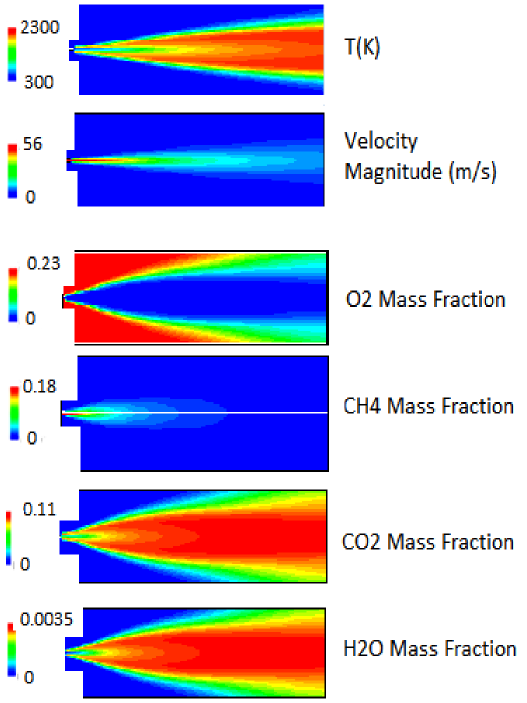


Figure 3. Results of fluent simulation of Non-Premixed CH_4-air flame using a One-step scheme

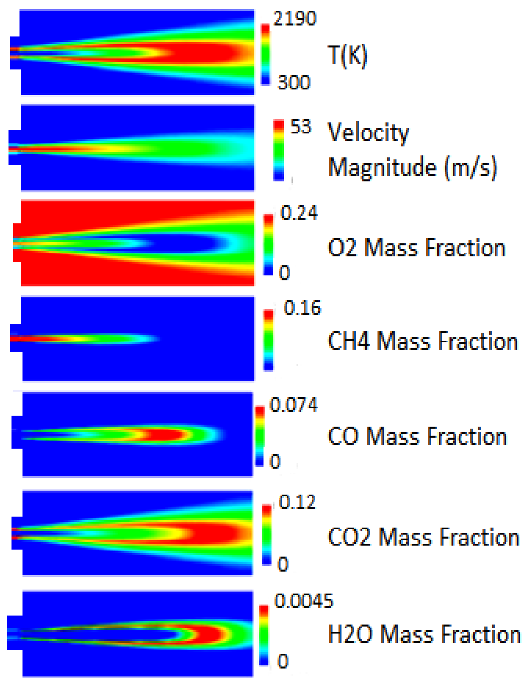


Figure 4. Results of fluent simulation of Non-Premixed CH_4-air flame using an 8-step scheme

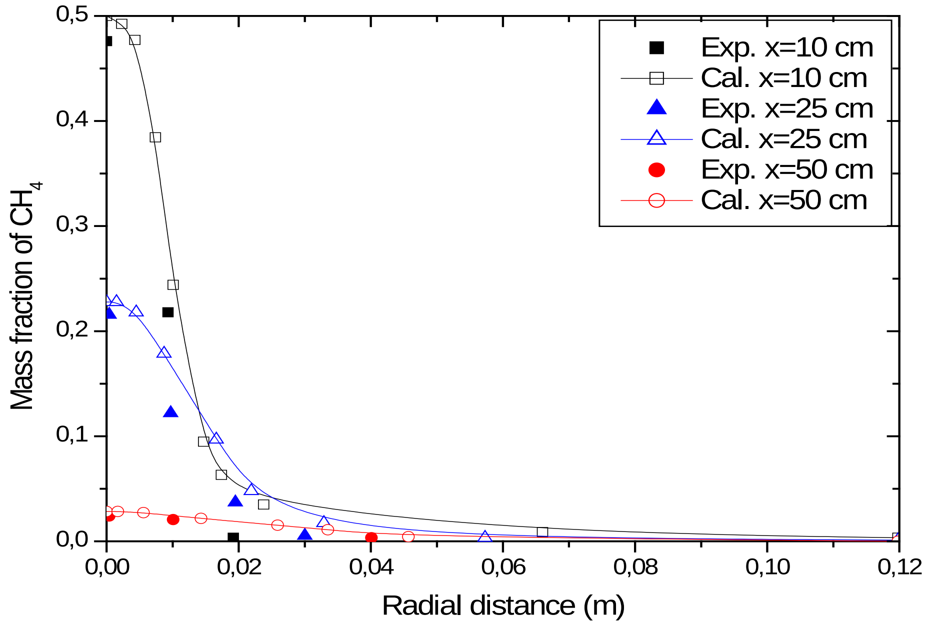


Figure 5. Radial CH_4 mole fraction profiles at several axial locations.

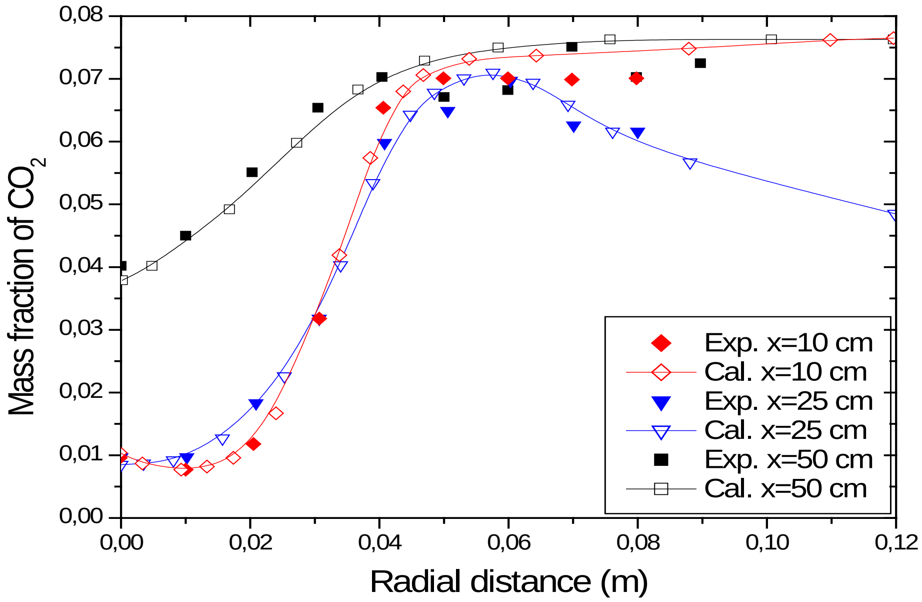


Figure 6. Radial CO_2 mole fraction profiles at several axial locations.

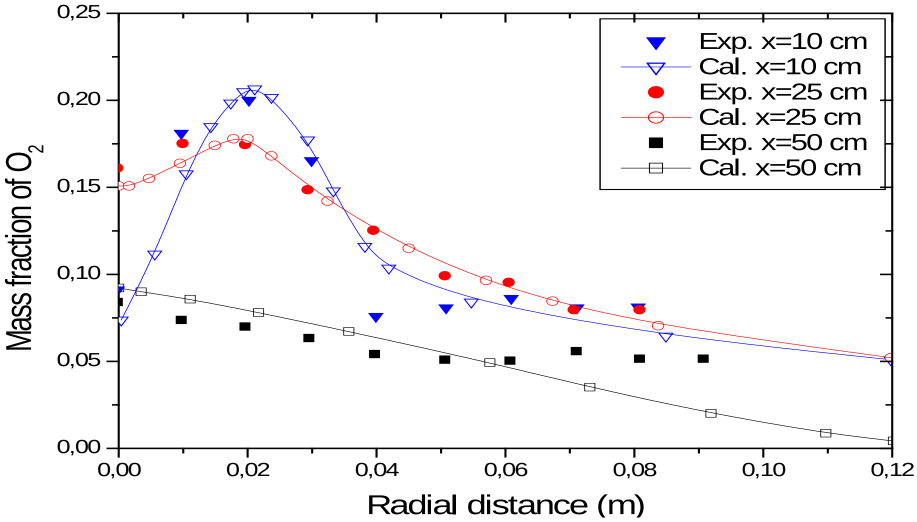


Figure 7. Radial O_2 mole fraction profiles at several axial locations.

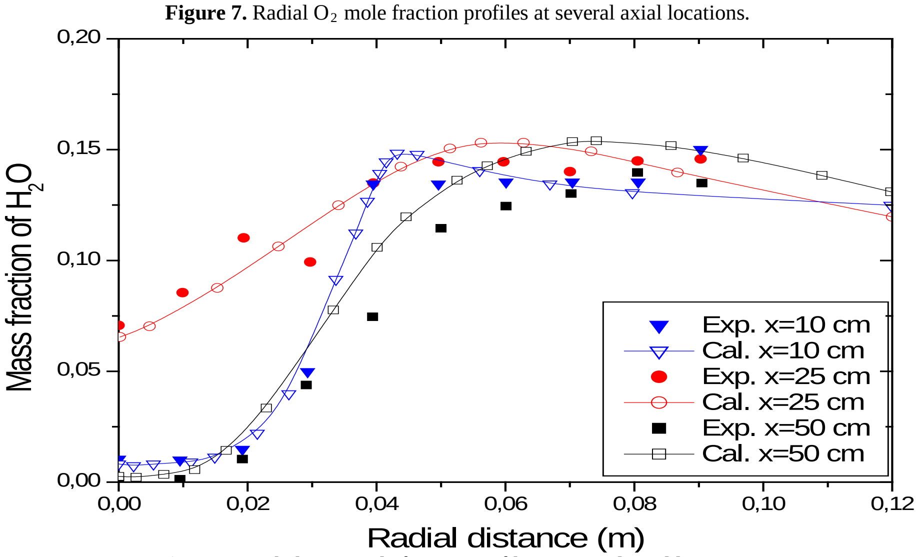


Figure 8: Radial H_2O mole fraction profiles at several axial locations.

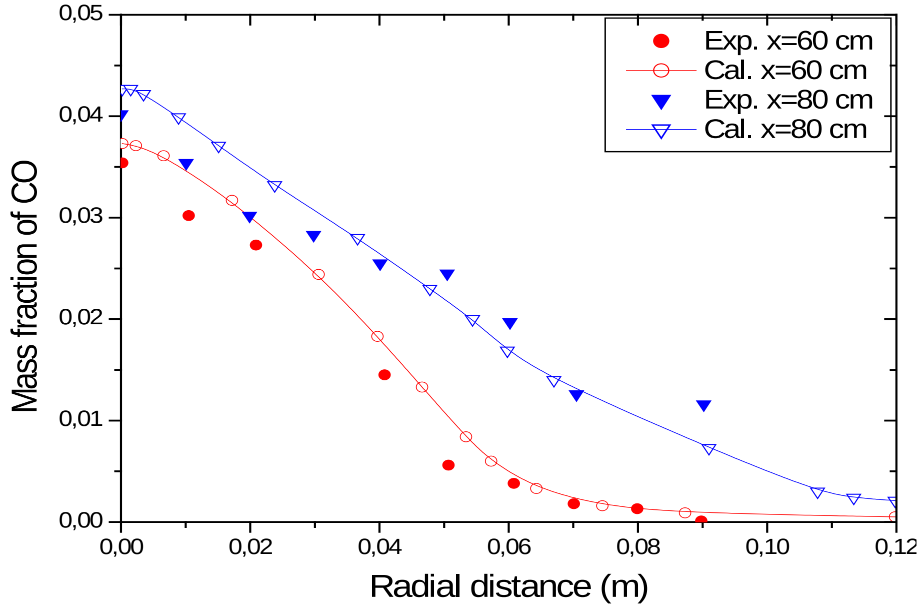


Figure 9. Radial CO mole fraction profiles at several axial locations.

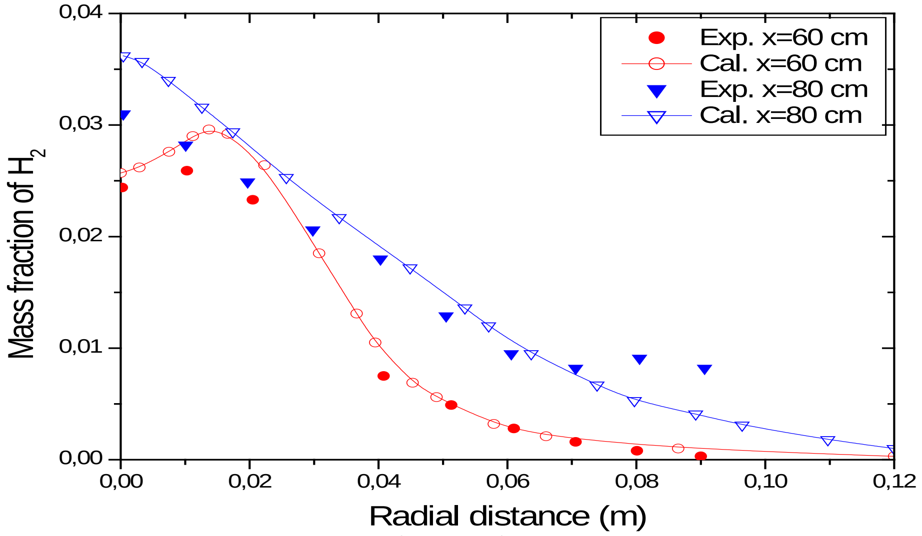


Figure 10. Radial H_2 mole fraction profiles at several axial locations.

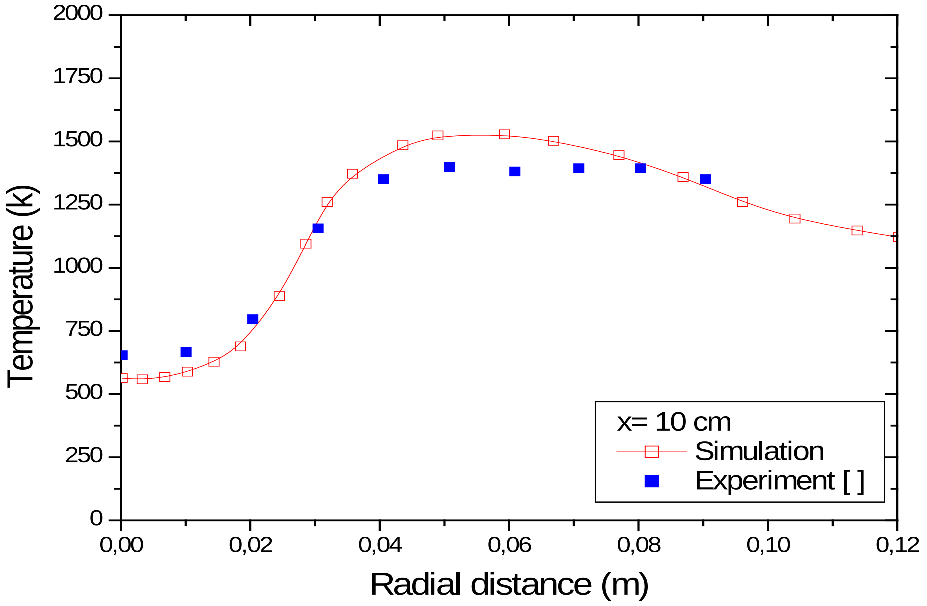


Figure 11. Temperature profile at x=10 cm.

7. Conclusion

The main results are:

- The 8-step reaction mechanism was successfully implanted into the Fluent.
- The Eddy-Dissipation Concept (EDC), which has been successfully used in RANS calculations of turbulent diffusion flames, has been formulated as a combustion model for RANS simulations of turbulent jet diffusion flames. The model has been applied in a simulation natural gas/air flame.
- The results are compared with experimental data for the temperature and various chemical species. The agreement is very reasonable for all quantities.

Future research work is needed to be done on:

- Using a reduced chemical kinetics mechanism for NO_x emission prediction in natural gas combustion.
- Adoption of more reasonable turbulence-chemistry model interaction for multi-step chemical reaction equations.

References

[1] Simmie J. M. (2003), detailed chemical kinetic models for the combustion of hydrocarbon fuels, Progress in Energy and Combustion Science, Vol. 29, p. 599-634.

[2] Guessab A., Aris A.E.K, Bounif A. and Gokalp I., Numerical Analysis of Confined Laminar Diffusion Flame: Effects of Chemical Kinetic Mechanisms, Int. J. of Advanced Research in Engineering and Technology, Vol. 4, January, pp. 59-78, (2013).

[3] Davidenko D. M., Gökalp I., Dufour E., Magre P. (2005), Numerical simulation of supersonic combustion with CH_4-H_2 fuel, European Conference for Aerospace Sciences (EUCASS), Moscow, Russia, 4-7 July.

[4] Westbrook, C. K., Applying Chemical Kinetics to Natural Gas Combustion Problems, Report No. PB-86-168770/XAB, Lawrence Livermore National Laboratory, Livermore, Cal., USA, (1985).

[5] Glarborg, P., Miller, J. A., Kee, R. J., Kinetic Modeling and Sensitivity Anal y sis of Nitrogen Oxide ormation in Well Stirred Reactors, Combustion and Flame, 65 (1986), 2, pp. 177-202

[6] Miller, J. A., Bow man, C. T., Mechanism and Modeling of Nitrogen Chemistry in Combustion, Progress in Energy and Combustion Sciences, 15 (1989), 4, pp. 287-338.

[7] Konnov, A. A., De tailed Reaction Mechanism for Small Hydrocarbons Combustion, (2000) Release 0.5, http://homepages.vub.ac.be/~akonnov/

[8] Huges, K. J., et. al., Development and Testing of a Comprehensive Chemical Mechanism for the Oxidation of Methane, International Journal of Chemical Kinetics, 33 (2001), 9, pp. 515-538.

[9] Dagaut P. (2002), on the kinetics of hydrocarbon oxidation from natural gas to kerosene and diesel fuel, Phys. Chem. Chem. Phys., Vol. 4, p. 2079–2094.

[10] The Leeds methane oxidation mechanism, http://www.chem.leeds.ac.uk/Combustion/methane.htm.

[11] San Diego Mechanism 2003/08/30, http://maemail.ucsd.edu/~combustion/cermech/olderversions/sandiego20030830/

[12] GRI-Mech v.3.0, http://www.me.berke ley.edu/gri_mech.

[13] Westbrook, C. K., Dryer, F. L., Simplified Reaction Mechanisms for the Oxidation of Hydrocarbon Fuels in Flames, Combustion Sciences and Technologies, 27(1981), 1-2, pp. 31-43.

[14] Jones, W. P., Lindstedt, R. P., Global Reaction Schemes for Hydrocarbon Combustion, Combustion and Flame, 73 (1988), 3, pp. 233-249.

[15] Kazakov A., Frenklach M., Reduced Reaction Sets based on GRI-Mech 1.2, http://www.me.berkeley.edu/drm/

[16] Yungster S., Rabinowitz M. J. (1994), Computation of shock-induced combustion using a detailed methane-air mechanism, Journal of Propulsion and Power, Vol. 10, No. 5, p. 609-617.

[17] Petersen E. L., Hanson R. K. (1999), Reduced kinetics mechanisms for ram accelerator combustion, Journal of Propulsion and Power, Vol. 15, No. 4, p. 591-600.

[18] Hyer P., Stocker D. and Clar I.O., Gravitational Effects on Laminar Diffusion Flames, Creare. X Users' Group Meeting Proceedings, pp. 345-372, 1991.

[19] Li S. C., Williams F. A. (2002), Reaction mechanisms for methane ignition, Journal of Engineering for Gas Turbines andPower, Vol. 124, p. 471-480.

[20] S.M. CANNON *et al*, PDF Modeling of lean premixed combustion using in situ tabulated chemistry, Comb. & Flame 119:223-252(1999)

[21] M.Jazbec *et al*, Simulation of the ignition of lean methane mixtures using CFD modeling and a reduced chemistry mechanism, Elsevier App. Math. Modeling 24 (2000) 689-696.

[22] A.L. Sanchez *et al*, The reduced kinetic description of lean premixed combustion, Comb. & Flame 123:436-464 (2000).

[23] Lewis M.H. and Smoot L.D., Turbulent Gaseous Part I: Theory and Local Species Concentration Measurements, J. of Propulsion and Power, Vol. 42, pp. 183-196, 2001.

[24] FLUENT. 2009. "Theory Guide: Release 12.0." Last modified January 23, 2009.

[25] Jones, W. P., and Launder, B. E. (1972), "The Prediction of Laminarization with a Two-Equation Model of Turbulence", International Journal of Heat and Mass Transfer, vol. 15, 1972, pp. 301-314.

[26] Pope S.B. (1978). An explantation of the turbulent round-jet/plane-jet anomaly, AIAA Journal, Vol. 16, No. 3, p. 279-281.

[27] Magnussen B, Hjertager BH (1976) 16th symposium (int.) on combustion, 719-729, The Combustion Institute, Pittsburgh.

JJMIE
Jordan Journal of Mechanical and Industrial Engineering
Volume 8 Number 2, April. 2014
ISSN 1995-6665
Pages 76 - 80

Formaldehyde Emissions of Gasoline Mixed with Alcohol Fuels and Influence Factors

Hao Chen[a,b], Lu Yanga, Penghui Zhanga, Jiang Li[a], Li-min Geng[a,b], Zhi-yi Ma[b]

[a] *School of Automobile, Chang'an University, Xi'an, China, the South Second-ring Road, 710064, Xi'an, China.*
[b] *Key laboratory of Shaanxi province for Development and Application of New Transportation Energy.*

Abstract

Alcohol fuels, including methanol and ethanol, are commonly mixed with gasoline. This paper designs the collection device for testing concentrations of formaldehyde emissions. Results indicate that compared with RON93 gasoline, formaldehyde emissions of M15, M25 and M85 respectively increase 7.2%, 26.5% and 46.6%, and those of E10 and E25 respectively increase 22.2% and 32.8%. Three way catalytic converter, test time, ignition advance angle and excess air coefficient have significant impacts on the formaldehyde concentrations. Two three-way catalytic converters will decrease the formaldehyde emission; the emission decreases with the test time and after ten minutes it tends to be stable; at 30% opening and 2600r·min^{-1}, 25°CA before TDC corresponds to the lowest formaldehyde emission; excess air coefficient should be controlled near 1.

Keywords: *Alcohol; Formaldehyde; Gasoline; Methanol; Ethanol.*

1. Introduction

Oil is the leading fuel in the world, and it is the most important and indispensable for transportation vehicles. In 2012, global oil consumption grew by 890,000 barrels per day, or 0.9%, below the historical average and oil had the weakest global growth rate among fossil fuels for the third consecutive year [1]. In 2012, the yield of automobiles in China is 19,277 thousand which are mainly consumed by the domestic market and the civilian automobiles reaches 120.89 million (including low-speed trucks), with growth of 14.3% over 2011 [2]. High economic growth ratio and high volume of automobiles commonly promote the oil consumption. As a result, China again recorded the largest increment to global consumption (+470,000barrels/day, +5%), although the growth rate was below the 10-year average [1]. Due to the poor reserves, consequential increase of dependence on foreign oil, which was 58.7% in 2012, obviously broke through the international cordon of energy security.

To maintain the high growth of economy, China is devoted to developing alternative fuels for automobiles. Alcohol fuels, methanol [3;4] and ethanol [5;6], are widely used to mix with gasoline. Ethanol is a kind of renewable energy which has been internationally accepted, while methanol derives from fossil fuels, mainly from natural gas [7;8] and in China from coal [4;9]. Before 2007, China concentrated on developing ethanol fuel from crops such as corn and wheat, which led to high food prices, affecting food safety. After that the government terminated the approval of ethanol production from agricultural crops, restricting ethanol production to non-grain feed-stocks (such as cassava and sweet sorghum) only; Accordingly, ethanol fuel faces, in China, resistance and it develops relatively slowly. On the other hand, although coal-based methanol is unhelpful for reducing GHG emissions, the high reserve of coal resource and the excess production capacity together push forward the development of fuel methanol industry.

As oxygen-contained fuel, both ethanol and methanol can reduce the HC and CO emissions [10-12]. Except for normal pollutants and GHG emissions, alcohol fuels have the problem of abnormal formaldehyde emissions. The aldehydes products, in partial oxidation of hydrocarbon fuels, include formaldehyde (HCHO), acetaldehyde (CH_3CHO), propionaldehyde (C_2H_5CHO), acrolein (C_2H_3CHO), aldehyde (C_3H_7CHO), etc. Generally, formaldehyde, the partial oxidation of engine emission, mainly comes from unburned HC and exhaust system. The flow condition of the gas in the exhaust pipe is complex. Temperature range is about 1500K ~ 800K, and the residence time lasts for a few milliseconds. At high temperature, HC and CH_2O will be completely oxidized into CO and CO_2; at low temperature, the chemical reaction rate will be very low, and the composition of the exhaust gas will not change obviously. Among the aldehydes, formaldehyde is especially harmful to human health.

Nowadays, ignition times, concentrations of gas mixture, and emissions of gasoline engines are important when designed. Ignition time has a significant influence on performances and emissions of SI engines and optimal ignition time will lead to a better combustion and a low emission [13]. Generally, three-way catalytic converter is effective for reducing HC, CO and NO_X emissions [14-16]. Transformation efficiencies of HC, CO and NO_X are the highest when λ, the excess air coefficient, is equal to 1 (air/fuel ratio is equal to 14.7). Therefore, under closed-loop control oxygen sensor is installed in the exhaust system to send feedback signal to achieve the precise control for fluctuation range of λ (λ=1±0.03) [17-18].

This paper firstly studies the formaldehyde emissions of gasoline mixed with alcohol fuels to obtain the rules among the different fuels. Because the formaldehyde emissions are not considered in the engine design process, the parameters such as ignition times and excess air coefficient are suitable for engines fueled with methanol gasoline should be concerned. Accordingly, the influence factors of formaldehyde emissions are deeply researched.

2. Test Conditions

2.1. Test Engine and Instruments

Flyer M-TCE is a closed-loop control engine and its major parameters are listed in table 1.

Table 1. Engine parameters

Engine	M-TCE
Type	Inline 3 cylinder, multi-point EFI
Discharge/ mL	796
Maximum power/ kW (r·min^{-1})	37.5(6000)
Maximum torque/ N·m (r·min^{-1})	68.6(4600)
Compression ratio	9.3

2.2. Formaldehyde Collection and Test

2.2.1. Formaldehyde Collection Device

The test used an external pipe providing fresh air to dilute the emissions. The dilution ratio between fresh air flow and exhaust gas flow is 5:1, which ensures that formaldehyde concentrations will not exceed the test range. They are respectively pumped by two vacuum pumps connected to the 12V DC power supply and in the blends tube emissions are diluted and mixed for test. Sketch of the experimental setup is shown in Figure 1.

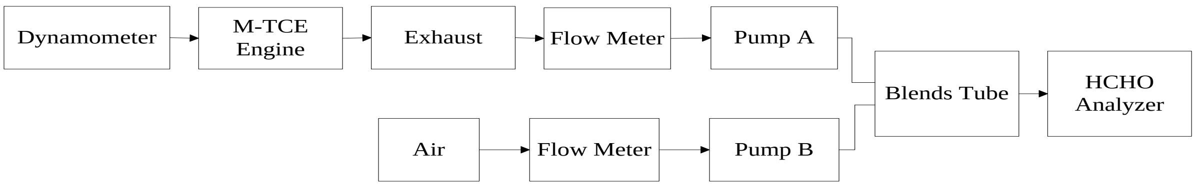


Figure 1. Test engine and instruments

2.2.2. Formaldehyde Analyzer

Formaldehyde concentrations in engine emissions can hardly be tested. In China, the phenol reagent method is adopted in the national standard (GB/T18204.26-2000) for testing the formaldehyde concentration in the air. Formaldehyde reacts with the phenol reagent, producing triazine which is oxidized by ferric iron to form a blue compound ion in acid solution. According to the color depth, colorimetry is used for quantitative calculation. This paper uses a portable indoor air testing instrument (GDYK-201S HCHO analyzer) for testing formaldehyde concentration.

2.3. Test Fuels

RON93 gasoline, methanol and ethanol are prepared for blending to get different mixture fuels. M15, M25 and M85 indicate that the methanol volume proportions are respectively 15%, 25% and 85%. E10 and E25 mean that the ethanol volume contents are 10% and 25%.

2.4. Concentration Calculation

The concentrations of formaldehyde at different temperatures and different pressures are calculated as (1):

$$C=\frac{C_0}{V_0}\times 10=\frac{C_0}{V_T\times\frac{273}{273+T}\times\frac{P}{101.3}}\times 10 \quad (1)$$

C: the actual measured formaldehyde concentration, mg·m^{-3};

C_0: formaldehyde analyzer display value, mg·L^{-1};

V_0: standard condition (20ºC, a pressure sampling volume), L;

10: Determination of colorimetric bottle solution volume, mL;

V_T: sampling volume, L;

T: sampling temperature, ºC;

P: sampling point of atmospheric pressure, kPa.

3. Results and Discussion

3.1. Formaldehyde Emissions of Gasoline Mixed with Alcohol Fuels

Formaldehyde emissions of gasoline mixed with alcohol fuels are shown in Figure 2. Formaldehyde is a kind of intermediate product in the combustion process. Temperature in the cylinder is so high that it is not suitable for the generation of formaldehyde, because the existing time in the high temperature gas is extremely short. Accordingly, it is mainly generated in the exhaust pipe from unburned methanol, and its generation depends on the amount of unburned methanol, exhaust temperature and reaction time. Formaldehyde derives from two reactions: oxidation which is an exothermic reaction shown in (2), and dehydrogenation which is an endothermic reaction as (3).

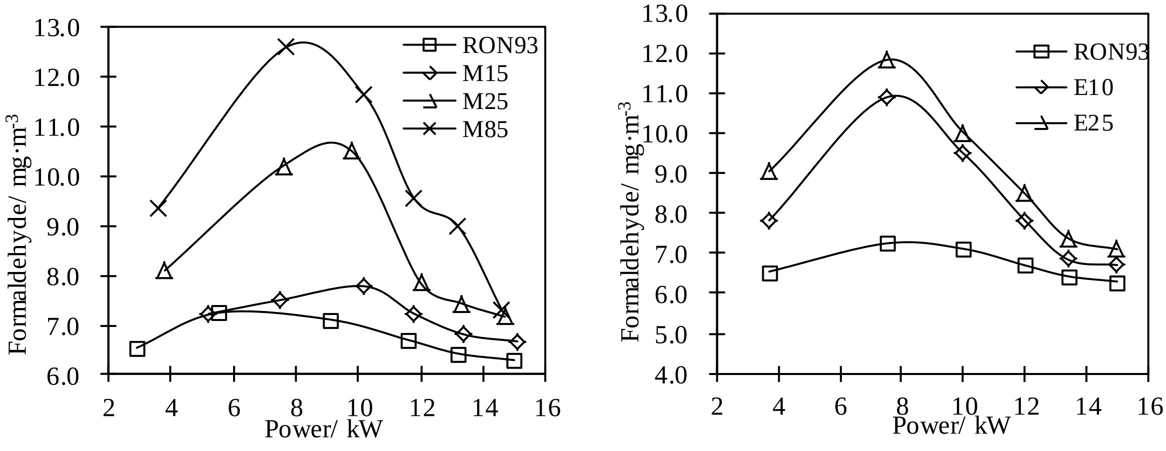
$$CH_3OH+\frac{1}{2}O_2\rightarrow CH_2O+H_2O \quad (2)$$

$$CH_3OH\rightarrow CH_2O+H_2 \quad (3)$$

Compared with RON93, formaldehyde emissions of M15, M25 and M85 respectively increase 7.2%, 26.5% and 46.6%; those of E10 and E25 respectively increase 22.2% and 32.8%. With the increase of methanol content, quality of unburned methanol increases and, thus, the formaldehyde emission increases. For ethanol, the rule is the same. The maximum value of formaldehyde for RON93 in the two curves are different. Influence Factors of Formaldehyde Emissions

3.1.1. Number of Three Way Catalytic Converter

At 30% opening of throttle valve and 2600r•min^{-1} of engine speed, formaldehyde emissions of different fuels are tested before a three-way catalytic converter (TWCC), after TWCC, and after two TWCCs, respectively, as shown in table 2. For all the fuels, different concentration values of formaldehyde emissions are obtained at different sampling points. Formaldehyde concentrations after TWCC are obviously higher than those before TWCC; however, after two TWCCs, the concentrations are apparently lower. For example, before TWCC, the formaldehyde emission concentration of M15 is 3.89 mg•m^{-3}, after TWCC, the concentration is 7.78 mg•m^{-3}, and after two TWCCs, the value is 2.49 mg/m^3. After TWCC, formaldehyde emissions of all the fuels are about twice as much as those before TWCC, mainly because that the unburned hydrocarbons and alcohols are partially oxidized into formaldehydes. When a TWCC is added, as intermediate products, formaldehydes decrease from 23.8% to 36.0% (for different fuels), because formaldehyde emissions are further oxidized into carbon dioxides and water.



(a) Methanol gasoline and gasoline (b) Ethanol gasoline and gasoline

Figure 2. Formaldehyde emissions

Table 2. Influence of three way catalytic converter on formaldehyde emissions

Sampling point	RON93	M15	M25	M85	E10	E25
Before three way catalytic converter (mg·m^{-3})	3.24	3.89	4.61	5.28	4.13	5.07
After three way catalytic converter (mg·m^{-3})	7.11	7.78	9.16	11.08	8.02	10.02
After two three way catalytic converters (mg·m^{-3})	2.07	2.49	3.36	4.03	2.85	3.83

3.1.2. Test Time

M15 and E10 are chosen for a comparison with RON93, shown in figure 3. Rules for other mixtures are the same. When the test time is short, the concentration values of formaldehyde emissions of different fuels are high. The concentrations decrease obviously with the test time. Ten minutes is the optimal time for a formaldehyde test, because the values tend to be stable and unchangeable. The result provides a correct and effective test condition for formaldehyde emissions.

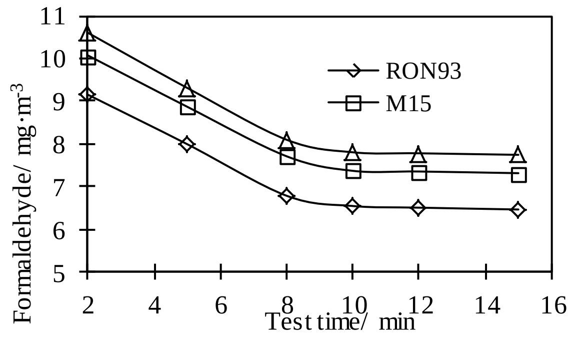


Figure 3. Formaldehyde emissions with test time

3.1.3. Ignition Advance Angle

In a certain operation condition, there is a best ignition advance angle which corresponds to the lowest formaldehyde emission. Figure 4 indicates variation rules of formaldehyde emissions with ignition advance angle. At 30% opening and 2600r•min^{-1} it is 25°CA before the TDC. Based on this, the advance or the delay of the ignition time will result in an increase of the formaldehyde emissions. When ignition advances, combustion advances as well, which leads to high negative work in the compress stroke. To achieve the same power, the fuel consumption increases. Unburned methanol and unburned hydrocarbons rise. As a result, they will surely be partially oxidized and formaldehyde emissions increase. If the ignition delays, after burning improves, which decreases the thermal efficiency. Similarly, the fuel consumptions and the emissions increase.

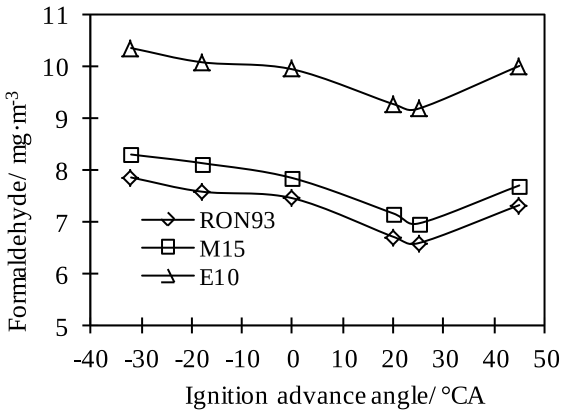


Figure 4. Formaldehyde emissions with ignition advance angle

3.1.4. Concentration of Gas Mixture

Excess air coefficient is adjusted within the range from 0.97 to 1.03. The test controlled λ value, by applying the virtual inlet air pressure signal and fuel injection quantity, can be well controlled. Consequently, the λ values can be adjusted. However, a closed-loop control is adopted in today's gasoline engine and the excess air coefficient is automatically adjusted when the ECU received the feedback signal from the oxygen sensor. The concentration of the mixed gas will be self-corrected to the above range. Therefore, in order to prevent the automatic correction of fuel injection quantity, the oxygen sensor is broken and the engine is under the open-loop control. Thus, the λ value can be changed as expected. The test data listed in table 3 show the formaldehyde emissions of the three fuels are the lowest when the excess air coefficient is equal to 0.987. Lower or higher excess air coefficient will increase the emission. Both rich mixture and lean mixture will result in the incomplete combustion and formaldehyde emissions will increase.

Table 3. Influence of excess air coefficient on formaldehyde emissions

Virtual voltage	Excess air coefficient	RON93 ($mg \cdot m^{-3}$)	M15 ($mg \cdot m^{-3}$)	E10 ($mg \cdot m^{-3}$)
3.3 (V)	1.289	17.64	18.25	19.72
3.6 (V)	1.187	11.45	13.98	14.65
4.2 (V)	0.987	6.74	7.65	8.01
4.5 (V)	0.89	9.20	10.25	10.96
4.8 (V)	0.801	16.93	17.02	18.34

4. Conclusion

Methanol gasoline and ethanol gasoline are the major alternative fuels for road transport vehicles in China. They are considered as clean fuels due to the high oxygen contents which contribute to the lower HC and CO emissions compared with gasoline. However, abnormal emissions, especially the formaldehyde emissions, increase obviously with the volume content.

A three-way catalytic converter is effective for reducing CO, HC and NO_X emissions. However, it contributes to the high formaldehyde emission. Solution method is adding a converter and the emission decreases obviously.

At 30% opening and $2600 r \cdot min^{-1}$, the ignition advance angle can be adjusted to 25°CA before TDC for the lowest formaldehyde emission. Comprehensive optimal data of ignition advance angles can be obtained through test at different loads and speeds.

Excess air coefficient is very important to engine performances and emissions. It can be proved that formaldehyde emissions are also lowest when λ is close to 1.

For experimenting the formaldehyde emissions, ten minutes is suggested for the test time.

Acknowledgement

The Project Supported by Natural Science Basic Research Plan in Shaanxi Province of China (Program No. 2014JQ7268) and the Special Fund for Basic Scientific Research of Central Colleges, Chang'an University (2013G1221018, 2013G3224019, CHD2012JC049).

References

[1] BP P.L.C.. BP Statistical Review of World Energy 2012. Retrieved January 31, 2013 from the World Wide Web: http://www.bp.com/content/dam/bp/pdf/statistical-review/statistical_review_of_world_ energy_2013.pdf.

[2] NBSC (National Bureau of Statistics of China). 2004-2012 statistical bulletin of national economic and social development of the P.R.C. From the World Wide Web: http://www.stats.gov.cn/ english/statisticaldata/yearlydata/.

[3] Y.H. Shen, "Methanol Gasoline Development in Foreign Countries and Enlightenment to China". Sino-global Energy, No. 12, 2010, 23-28 (in Chinese).

[4] C.J. Yang, B.J. Robert, "China's growing methanol economy and its implications for energy and the environment". Energy Policy, Vol. 41, 2012, 878-884.

[5] A.A. Adolf, S. Tomas, G. Andrea , K. Johan , S.C. LennyKoh, M.M. Simon, "Biofuels and their potential to aid the UK towards achieving emissions reduction policy targets". Renewable and Sustainable Energy Reviews, Vol. 16, No. 7, 2012, 5414-5422.

[6] Luciano Charlita de Freitas, Shinji Kaneko, "Ethanol demand in Brazil: Regional approach". Energy Policy, Vol. 39, No. 5, 2011, 2289-2298.

[7] Z. Wang, "Experimental Study on Combustion & Emissions of SI Engine Powered by Different Methanol-Gasoline Fuels". Master degree thesis. 2010. Tsinghua University.

[8] K.S. Anita, K.S. Athena, "Wind-hydrogen utilization for methanol production: An economy assessment in Iran". Renewable and Sustainable Energy Reviews, Vol. 15, No. 8, 2011, 3570-3574.

[9] F. Zhang, S.J. Shuai, Z. Wang, X. Zhang, J.X. Wang, "A detailed oxidation mechanism for the prediction of formaldehyde emission from methanol-gasoline SI engines". Proceedings of the Combustion Institute, Vol. 33, No. 2, 2011, 3151-3158.

[10] Y.C. Yao, J.H. Tsai, I.T Wang, "Emissions of gaseous pollutant from motorcycle powered by ethanol–gasoline blend". Applied Energy, Vol. 102, 2013, 93–100.

[11] L.W. Jia, M.Q. Shen, J. Wang, M.Q. Lin, "Influence of ethanol–gasoline blended fuel on emission characteristics from a four-stroke motorcycle engine". Journal of Hazardous Materials, Vol. 123, No. 1-3, 2005, 29–34.

[12] Q.H. Zhao, X.P. Wu, "CO/HC emissions analysis of engine used ethanol gasoline". Automobile Applied Technology, No.8, 2012, 35-37(in Chinese).

[13] J. Li, C.M. Gong, Y. Su, H.L. Dou, X.J. Liu, "Effect of injection and ignition timings on performance and emissions from a spark-ignition engine fueled with methanol", Fuel, Vol. 89, No. 12, 2010, 3919-3925.

[14] H. CHEN, Q.H. MA, L.M. GENG, "Influence of oxygen sensor on em ission and conversion efficiency". Journal of Zhengzhou University (Engineering Science), Vol. 28, No. 2, 2007, 93-96(in Chinese).

[15] N.S. Asad, Y.S. Ge, H. Zhao, "Aldehyde and BTX Emissions from a Light Duty Vehicle Fueled on Gasoline and Ethanol-Gasoline Blend, Operating with a ThreeWay Catalytic Converter". Jordan Journal of Mechanical and Industrial Engineering, Vol. 4, No. 3, 2010, 340-345.

[16] A. Takigawa, A. Matsunami, N. Arai, "Methane emission from automobile equipped with three-way catalytic converter while driving". Energy, Vol. 30, No. 2-4, 2005, 461-473.

[17] X.Y. Dong, T. Cheng, "Research of air/fuel ratio PI control and vehicle emission optimization, Equipment manufacturing technology", No.3, 2012, 4-7(in Chinese).

[18] F.H. Ma, J.J. Wang, W. Chen, X. Wu, Y. Li, Y. Wang, "Emission characteristic of turbocharged lean burn CNG engine". Chinese Internal Combustion Engine Engineering, Vol. 29, No. 2, 2008, 10-14(in Chinese).

JJMIE

Volume 8 Number 2, April. 2014
ISSN 1995-6665
Pages 82 - 93

Jordan Journal of Mechanical and Industrial Engineering

A Study of Experimental Temperature Measuring Techniques used in Metal Cutting

Ajay Goyal[1*], Suresh Dhiman[2], Shailendra Kumar[2], Rajesh Sharma[2]

[1]*Department of Mechanical Engineering, Mangalayathan University, Aligarh, INDIA*

[2] *Department of Mechanical Engineering, National Institute of Technology Hamirpur, INDIA*

Abstract

From the beginning of machining of materials, rise in tool, chip, and work piece temperature remains a problem for engineers. The excessive rise in temperature severely affects the tool life and the quality of the work piece. To check this issue, engineers and scientists are tirelessly investing their efforts. Measurement of the tool, chip, and work piece temperatures takes a vital breakthrough in this direction. Several methods are developed and tested from time to time. But none is found perfect, some are better at a certain situation but fails at another. The appropriate technique for a given problem depends on the situation under consideration, such as the ease of accessibility, situation dynamics, desired accuracy, spot size, and economics. These techniques are broadly categorized in three categories, namely analytical, experimental, and finite element methods. Experimental is more practical, and more accurate among these three anchors. In this paper, all experimental techniques for the measurement of tool, chip, and work piece temperatures distribution are studied in depth and presented in a user friendly concise manner.

Keywords: *Temperature Distribution, Metal Cutting, Cutting Variables.*

1. Introduction

During metal cutting, cutting parameters like optimum cutting speed, subsurface deformation, metallurgical structural alterations in the machined surface, and residual stresses in the finished part, each depends on maximum temperature, temperature gradient, and the rate of cooling at various points of tool and work piece. Not only this, the tool life, the development of new tool material, and other advances in manufacturing technology also depend on temperature rise and heat generation at three zones of heat generation. Thereby, it is often desirable to have an estimation / prediction of the generation of heat and the temperature rise at various points of tool, chip, and work piece, so that various parameters can be adjusted optimally beforehand to improve machinability.

Foundation of estimation of heat generation due to mechanical work was laid by Rumford [1]; further strengthened by Joule [2] by finding the mechanical equivalent of heat. While the application in metal cutting was first reported by Taylor [3], since then scientists and researchers have been developing various methods and techniques to estimate the temperature variations at various points of tool, chip, and work piece. These methods can be categorized in three broad categories, namely experimental, analytical, and finite element analysis-based methods. Each one has its own merits and demerits. In this paper all the experimental techniques for the measurement of heat generation (temperature rise) during metal cutting at tool and work piece, available in the relevant literature, are studied critically and presented in a user-friendly concise manner under the following subtitles: (i) Thermal paints technique; (ii) Thermocouple techniques -Tool-work thermocouple technique, Transverse thermocouple technique, and Embedded thermocouple technique; (iii) Infrared radiation pyrometer technique; (iv) Optical infrared radiation pyrometer technique; (v) Infra-red photography; (vi) Fine powder techniques; and (vii) Metallographic methods.

2. Study of Various Techniques

In 1798, Rumford's boring cannon experiment for detection of frictional heat generation proved that mechanical work can be converted into heat. This experiment laid the foundation of experimental analysis of mechanical equivalent of heat. However, no attempt was made to measure the mechanical equivalent of heat numerically. Over more than half a century later the mechanical equivalence of heat was successfully established by Joule [2] by envisioning a calorimetric method. Taylor and Quinney's [3] study of the generation of heat accompanied by plastic strain strengthened the concept of mechanical equivalence. They measured the temperature of various specimens under tensile test during

* Corresponding author. e-mail: ajay.goyal2411@gmail.com.

  - Volume 8, Number 2 (ISSN 1995-6665)

the formation of creep and they found that the major amount of plastic energy, used for deforming the specimen, gets converted into heat. In metal cutting application, Taylor [4] studied the relation between cutting velocity and tool life, and developed a tool life equation. He also invented a tough, wear resistant, heat resistant, and hard tool material (HSS) which is still in use. Since then, scientists and researchers have been developing various methods and techniques to estimate the temperature variations at various points of tool, chip, and work piece. These methods can be categorized in three broad categories, namely experimental, analytical, and finite element analysis-based methods. Here, developments in the experimental techniques for the measurements of the temperature rise (heat generation) during metal cutting are explained with the help of self-explanatory flow charts and tables. Articles [5-19] may be referred for finite element analysis and analytical methods.

2.1. Thermal Paint Technique

This is one of the simplest and most economical techniques used for the measurement of temperature at various points (Figure 1) of tool. The technique was used by Schallbroach and Lang [20], Bickel and Widmer [21] among others. Particularly, Okushima and Shimoda [23] used this technique to determine the temperature distribution at joints of the tool. Rossetto and Koch [24] investigated the temperature distribution on the tool flank surface and developed the isotherms of temperature at various points with respect to flank surface distance in x and y direction at a specified cutting variable, as shown in Figure 2. The results obtained with this technique are generally considered approximate and confirmation of results from any other technique is recommended.

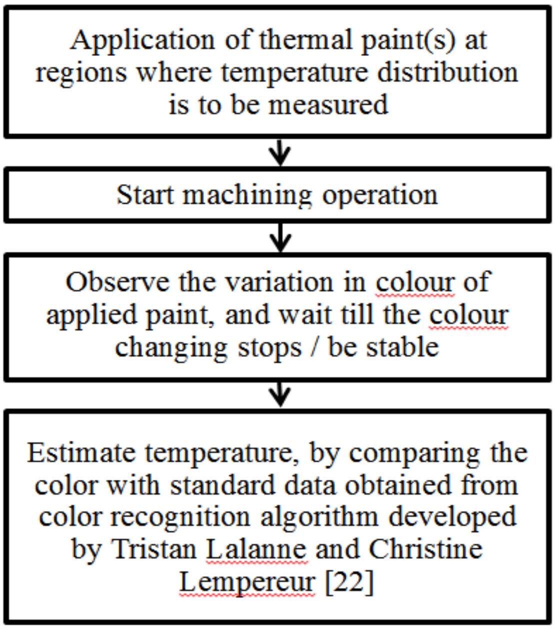


Figure 1. Process flowchart of thermal paint technique

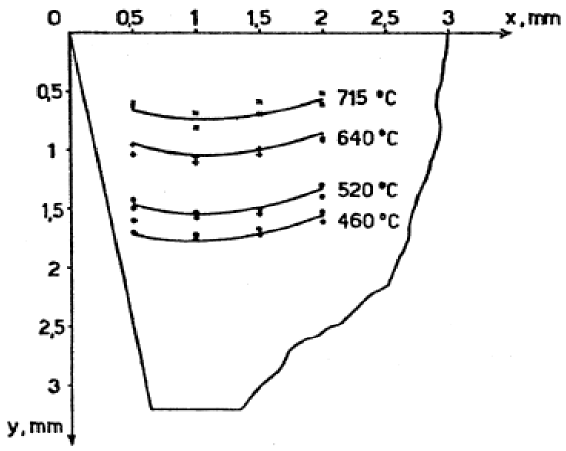


Figure 2. Experimental data and corresponding isotherms, work material: AISI 1040 steel; tool: cemented carbide (P20); depth of cut: 2 mm; feed: 0.428 mm/rev; cutting speed: 3.33 m/s [24]

2.2. Thermocouple Techniques

The technique is based on Seeback effect. According to this effect, temperature difference produced between hot and cold junctions of two dissimilar metals produces voltage difference between the junctions [25]. This voltage difference is calibrated to measure temperature rise at cutting zones [26]. This method is useful to relate various cutting parameters (speed, feed, and depth of cut) to the variation of temperature. Advantages of using thermocouples for the measurement of temperature include its simplicity, easiness of measurement, flexibility, and low cost. Stephenson [27] predicts that this method gives very good results when tungsten carbide tool insert is used in single point tool operations. Moreover, Stephenson mentions that this method is inappropriate for rough cutting at high speeds. There are basically three types of thermocouple techniques as shown in Figure 3.

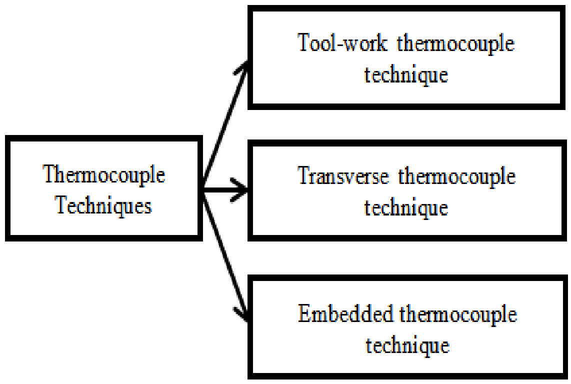


Figure 3. Types of thermocouple techniques

2.2.1. Tool-Work Thermocouple Technique

The arrangement of this technique is very simple; setup is illustrated in Figure 4 and the process is charted in Figure 5. Shaw [28] predicts that the method is easy to determine the temperature variation on tool work piece interface during metal cutting. Accurate calibration of the tool and work piece materials as a thermocouple pair is difficult. The summary of work carried out on the technique is tabulated in Table 1. The temperature rise at single point of tool can be observed by this technique. Further, the technique is widely used in case of tool inserts. In order to find the temperature rise distribution at various points of the tool, this technique could not be used in single setup.

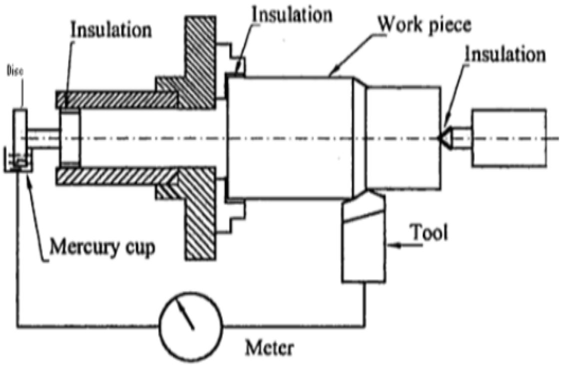


Figure 4. Schematic experimental setup for measuring average chip-tool interface temperature using tool-work thermo-couple technique [29]

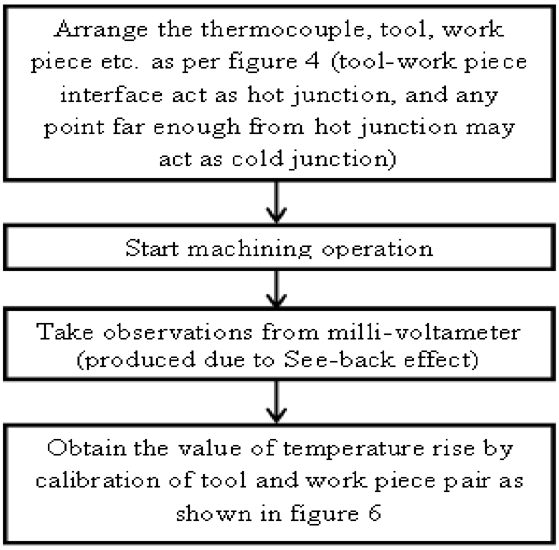


Figure 5. Process flowchart of tool Work Thermocouple Technique

Table 1. Summary of major works on tool-work thermocouple technique

S. No.	Scientist	Work material	Tool material	Conclusion
1	L.B.Abhang and M. Hameedullah [12]	EN31 steel alloy	Carbide	1. With increase in the value of cutting variables (velocity, feed and depth of cut), temperature increases 2. With increase in nose radius, temperature decreases
2	Trigger [13] Grzesik [14]	AISI 1045 AISI 304	Carbide	Increase in cutting speed, cutting forces & temperature decreases
3	S.K. Chaudhary G.Bartarya [15]	EN 24 steel	HSS (10% Co)	Increase in cutting speed and feed rate cutting zone temperature increases
4	Federico Reginalot et al. [16]	Hardened steel	Multilayer coated carbide	Temperature near the rake face increases significantly when the depth of cut changes from 0.2 to 0.4 mm.
5	B. Fnides et al. [17]	AISI H11 steel treated to 50 HRC	Mixed ceramic tool	Results are similar to the results as obtained by Federico et. al. [16]
6	H. Ay and Yang [18]	Copper, cast iron, aluminum 6061 and AISI 1045 steel	Carbide	1. More oscillations in temperature in ductile material in comparison to hard machining materials. 2. With increase in cutting variables, temperature increases. 3. With increase in nose radius, temperature decreases.

2.2.2. Transverse Thermocouple Technique

The tool-work thermocouple technique is used to measure the average temperature at tool work interface, but the temperature variation at different points and faces of the tool is difficult to analyze with this method. To overcome this problem, transverse thermocouple technique was developed by Arndt and Brown [36], which is capable of notifying temperature at various points on the tool with the help of a moving probe as detailed in Figure 7. In this technique, a high speed steel tool and cemented carbide probe or vice versa are used. The results obtained by Arndt and Brown are given in Figures 8, 9, and 10.

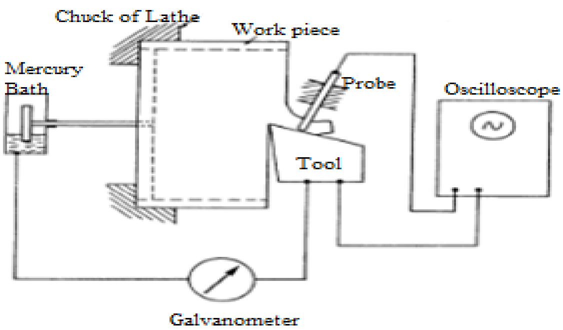


Figure 7. Experimental setup for transverse thermocouple technique, used to cut AISI 1011 steel at a cutting speed of 0.762 m/s. [36]

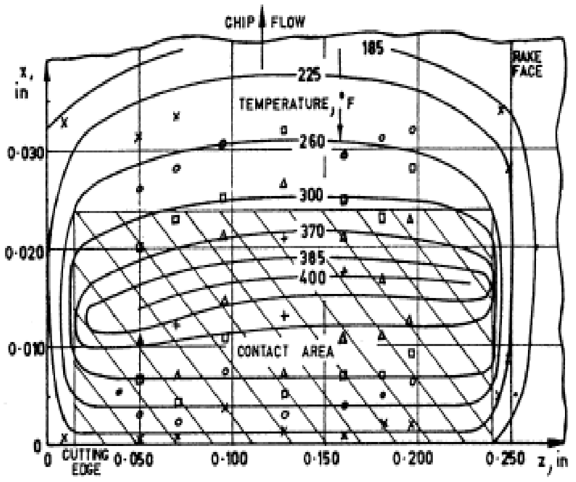


Figure 8. Temperature isotherms on rake face [36]

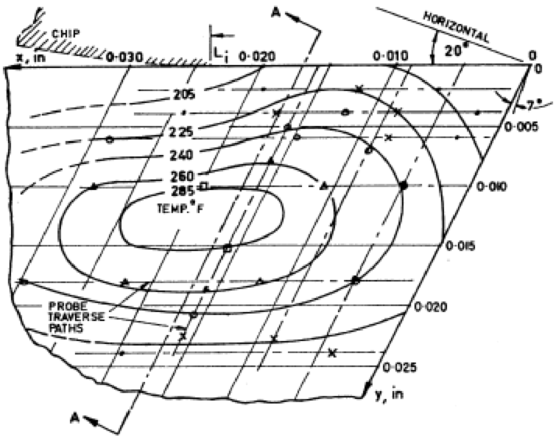


Figure 9. Temperature isotherms on end face [36]

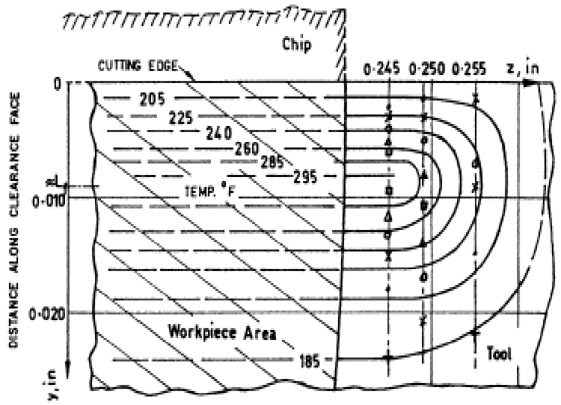


Figure 10. Temperature isotherms on clearance face [36]

2.2.3. Embedded Thermocouple Technique

In operations like milling, grinding, etc., where other two thermocouple techniques do not work, embedded thermocouple can serve the purpose. The experimental setup is illustrated in Figure 11a, and the process is given in Figure12. Yang *et al*. [37] used 9 K type thermocouples along all three surfaces of the tool for temperature measurement. Kitagawa *et al*. [38] created a micro thermocouple between an alumina- coated tungsten wire and the carbide inserts. Sullivan and Cotterell [39] measured the temperature in the turning of aluminum 6082-T6 by using two thermocouples in the work piece. Ren *et al*. [40] evaluated the cutting temperatures in hard turning of titanium alloy and chromium hard facings using thermocouples located between the tool (PCBN) and its shim. Nee *et al*. [41], Rowe *et al*. [42], Batako *et al*. [43], Lefebvre *et al*. [44] and Fang *et al*. [45] used foil / work piece embedded thermocouple technique for measuring temperatures of tool and work piece in grinding process. This type of thermocouple minimizes chances of fire hazards and measuring errors in high speed dry cutting of magnesium alloys. Hirao [46] devised a wire thermocouple setup to measure the temperature in the flank face of the tool. Similar setup was made by Black *et al*. [47] and Dewes *et al*. [48].

To overcome major problems of the only measurement of mean temperatures with which it is difficult to predict wear, fracture, etc., associated with of the embedded and single wire thermocouples, a new device – a thin film thermocouple – was proposed by Shinozuka *et al*. [49; 50]. Similar innovations were also carried out by Weinert *et al*. [51] and Biermann *et al*. [52]. This modified setup enabled temperature measurement to be close to the working zone. However, this method suffered from the problem of insufficient adhesion (between the metal coatings and the cutting inserts).

The temperature of surface cannot be measured directly while it could be estimated by extrapolating the graph. But sometimes the extrapolation of the graph is difficult as in the case of hyperbola (Figure11c). To tackle this problem, the graph may be plotted in log-log graph paper, as shown in Figure 11d. The technique has short response times of the order of 10 μs.

The major work on the technique is summarized in Table 2. The limitations of the embedded thermocouples technique include the following: (i) Temperature of surface cannot be measured directly while it could be estimated by extrapolation; (ii) Drilling of large number of holes may result in wrong results due to uneven distribution of temperature; (iii) In some cases, it is difficult and costly to drill holes, such as ceramics, cemented carbides, and hardened HSS tools; (iv) Thermocouples have limited transient response due to their mass and distance from the points of intimate contact.

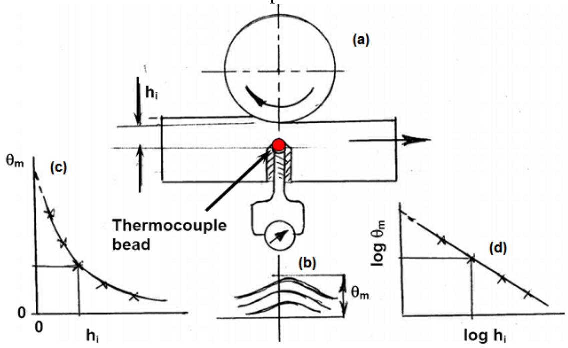


Figure 11. (a) Experimental setup of embedded Thermo-couple technique;

(b) Variation of temperature with respect to distance during machining;

(c) Variation of temperature with respect to height h_i on a simple graph;

(d) Variation of temperature with respect to h_i on a log-log graph [53]

Table 2. Summary of major works on embedded thermocouple technique

S.No.	Scientist	Investigation	Conclusion	Remarks
1	Chao et al [21]	The temperature variation at various points for various polymers by deforming them at different strain rates	Measurable temperature rise for low to medium strain rates	Failed to apply this technique successfully for measurement of temperature variation at higher strain rates
2	D. Rittel [22]	Transient temperature changes in three different polymers subjected to high impact velocity	Developed experimental results of temperature variation with reference to different strain rates	The results show that this technique can be applied for other materials
3	Rall and Giedt [23]	Tool-chip interface temperature using HSS tool (0^0 and 15^0 back rake angles)	Plotted temperature variation at different points at the interface by extrapolation on log-log graph	--
4	Qureshi and Koenigsberger [24]	Temperature variation at various surface points of the tool	Found the maximum cutting temperature was not at the cutting edge but at some distance away from it	--
5	Kusters [25]	Temperature variation of cemented carbide tool over the entire surface area of the tool with in a distance of 0.2mm from the surface of the tool	Isotherms on the surface of tool were plotted by using extrapolation method	Nearby 400 holes were drilled on the surface of cemented carbide tool, 30Mn4 steel was used as work piece at a cutting speed of 1.58m/s

2.3. Infrared Radiation (IR) Pyrometer Technique

It is a photo electric effect [59] based technique, designed and developed by Schwerd [61] and Kraemer [62], respectively. It can measure the temperature along the shear zone and tool flank accurately as shown in Figure 13. The technique was further modified by Lenz [63] by reducing the exposure time of radiations to PbS cell, so that measurement could be taken along clearance face.

The process is briefly explained in Figure14. Since the resistance of the PbS cell is sensitive to the changes in its ambient temperature as well as to the infrared radiation, to take care of this, the cell was kept at a constant temperature in an ice bath. The major work on the technique is summarized briefly in Table 3.

Table 3: Summary of major work on infrared radiation pyrometer technique

S. No.	Scientist	Operation	Region of interest	Tool / work material	Observation
1	Mayer and Shaw [31]	Grinding	Ground surface of work piece	Al_2O_3 grinding wheel / AISI 52100 steel	1. Plotted surface temperature variation with chip thickness 2. Plotted surface temperature variation with wheel speed
2	Reichenbach [32]	Planing	Shear plane, flank surface	-	For application of the method minimum temperature is 232^0C, hence the complete isotherm cannot be plotted
3	Chao et. al. [33]	Turning	Flank surface	AISI 1018 and AISI 52100 steel	1. Increasing feed or speed results in an increase of tool flank temperatures 2. A gradual shift of the maximum temperature away from the tool edge
4	Lenz [34]	Turning	Clearance face	-	Established isotherms for the clearance surface of the tool (with a little modification in setup)

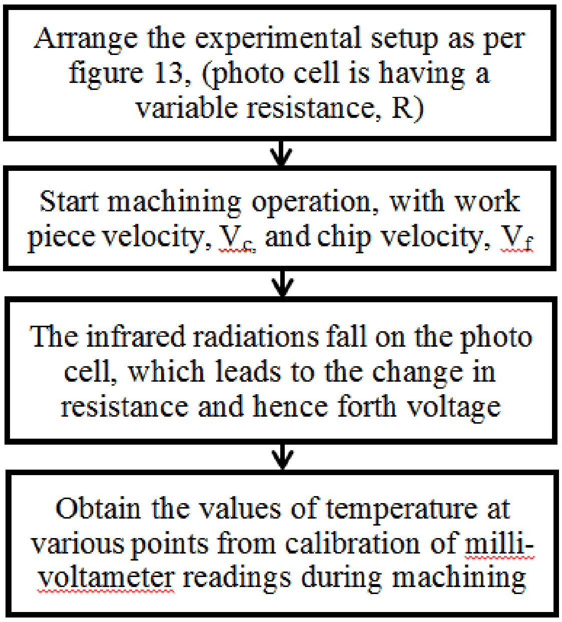


Figure 14. Process Flow Chart for IR Technique Using PbS Photocell

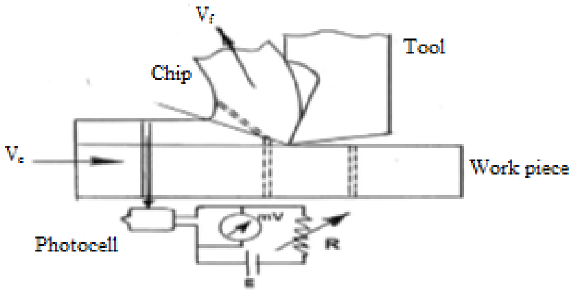


Figure 13. Experimental setup for IR pyrometers [60]

2.4. Optical Infrared Radiation Pyrometer Technique

This method is similar to IR pyrometer technique explained in (2.3), with the difference of an optical mechanism. The optical mechanism collects radiation instead to direct impingement of radiations to PbS cell, thus producing better results and reducing the exposure time. This technique is also implemented with the use of tool inserts. Major work on the technique is tabulated in Table 4.

Table 4: Summary of major works on optical infrared radiation pyrometer technique

S.No.	Scientist	Region of interest	Observation
1	Lenz [35-37]	Chip tool interface	The temperature distribution on the tool face
2	Friedman and Lenz [38]	Upper surface of chip	1.Temperature increases almost linearly with the distance from the origin of the chip formation 2. Temperature increases with decrease in feed, 3. Temperature decreases with increase in cutting speed, 4. Variation of temperature with width is small except towards the edges, 5. Influence of tool material was negligible
3	Prins [39]	--	Studied the influence of tool wear, tool geometry, feed, and cutting speed on the temperature distribution. The study is concluded on the followings: 1.The maximum tool temperature increases with increase in speed and feed, 2. A larger corner radius can reduce the temperature of the tool tip, 3. A larger included angle and a smaller cutting edge angle reduces the temperature of the tool tip
4	Ueda et al. [40]	Abrasive Grains on wheel surface	Found the mean temperature (as 820°C) for abrasive particles of Al_2O_3, A36K7VC Grinding wheel for grinding of AISI 1055 Steel, 200VHN at wheel speed of 28.85 m/s, and work speed of 0.167 m/s with down feed of 20micro meter.
5	Ueda et al. [41]	Ground Surface of Work Piece	Observed the temperature variation with the depth below the ground surface, for Si3N4, SiC, and Al2O3 respectively using diamond grinding wheel. Highest temperature was obtained with Si3N4 work material whose grinding power was largest. The mean value was estimated to be 800^0C
6	Ueda et al. [42]		1.Observed the temperature distribution of Al_2O_3, CBN and diamond during machining and predicted that temperature variation in direct proportion to thermal conductivity 2.Showed that the maximum temperature of the abrasive grains at the cutting point was found to reach close to the melting temperature of the work material
7	Ueda et al. [43]	Rake face	The temperature of a diamond tool increased with increase in the cutting speed and reached a maximum value of 190^0C
8	Parker and Marshall [44]	Rail Road wheels and brake blocks	Maximum temperature of 800^0C was recorded

2.5. Infrared Photographic Technique

Boothroyd [78; 79] developed this technique to measure the temperature distribution in the shear zone and at the chip–tool interface during machining. The experimental setup and process are given in the Figure 15 and Figure 16, respectively. This technique is widely used in case of the use of tool inserts.

Major advantages of the technique are: (i) the distribution of temperature can be analyzed over a wider region due to formation of visual image; (ii) the measurements can be taken in hazardous environment; (iii) a non-destructive method to analyze variation of temperature; (iv) very fast response and exposure time; (v) measurement without inter-reaction, i.e., no influence on the measuring objects; (vi) long lasting measurement; and (vii) no mechanical wear.

Limitations of this technique include the followings: (i) the camera requires an exposure of 10-15 seconds to record the data of the tool/work piece; (ii) preheating of the work piece is necessary so that it could be sensed by the photographic film; (iii) the camera is costly; (iv) emissivity of work piece is never the same at all points and keeps changing during the operation, which affects the quality of the picture; and (v) ability to detect the surface temperature only.

Jeelani [80] modified the technique by constructing a special light-tight enclosure around the lathe to eliminate the exposure of any outside light, and measure the temperature distribution in the machining of annealed 18% Ni Maraging steel in the cutting speed range of 0.406–0.813 m/s. The results obtained were better than those of Boothroyd [79]. The modification eliminates the need to preheat the work piece.

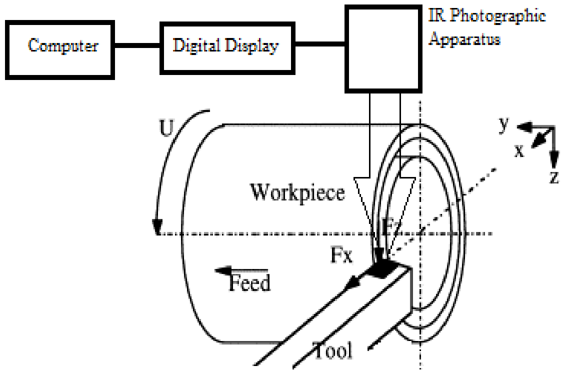


Figure 15. Experimental setup for infrared photographic technique

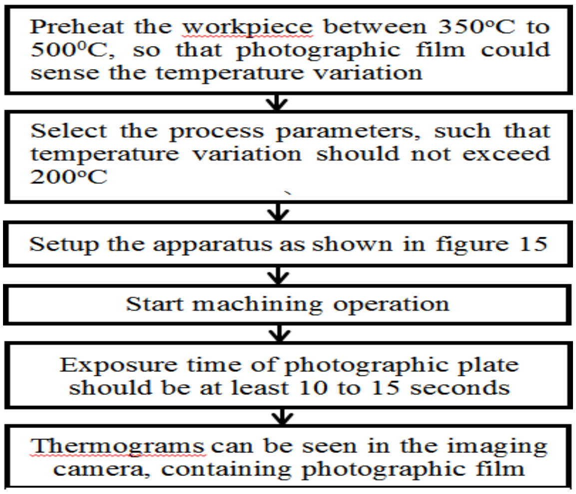


Figure 16. Process flow chart for infrared photographic technique

2.6. Fine Powder Technique

Kato *et al.* developed the technique [81] to determine the temperature distribution at various points on the surface of the tool using fine powder(s) of constant melting point. Experimental setup and process are briefly described in Figure 17 and Figure 18, respectively.

The melting points of commonly used powders in the technique are listed in Table 5. For proper adhesion of powder on the tool, aqueous solution of sodium silicate may be used. There is no need of calibration since all the used powders are having constant melting points.

Kato *et al*. [81] used NaCl, $PbCl_2$, and KNO_3 powders (10–20 μm) to determine the temperature distribution on carbide (P20), cermet, and ceramics tool (0^0 rake angle and 5^0 clearance angle) while machining AISI 1025 steel at cutting speeds 1.167 m/s and 2.5 m/s, and obtained micrographs of the sandwich surface of the tool for both the cutting speeds. From these graphs, the temperature distribution contours, along the rake face (*x*-direction) and the clearance face (*z*-direction) for carbide, cermet, and ceramic tools (Figures 19, 20 and 21, respectively) by superimposing the isothermal lines, were obtained.

Table 5. Melting point of commonly used powders [81]

Chemical Composition	**Melting Point (^{0} C)**
NaCl	800
KCl	776
CdCl	568
$PbCl_2$	501
AgCl	455
Zn	419
KNO_3	339
Pb	327.4
$SnCl_2$	246.8
Sn	231.9

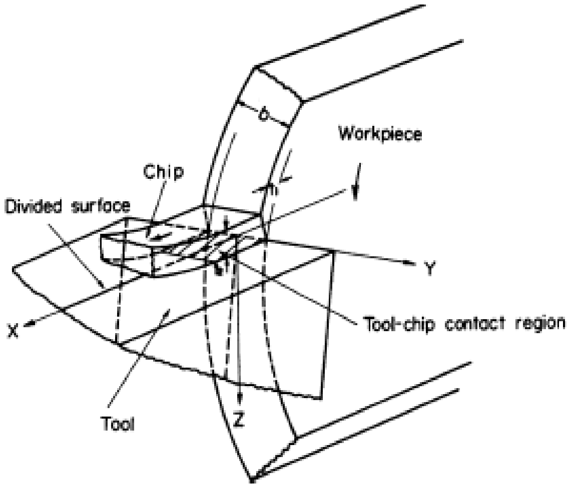


Figure 17. Schematic of the experimental method used for determining the temperature distribution in the tool using fine powder technique [81]

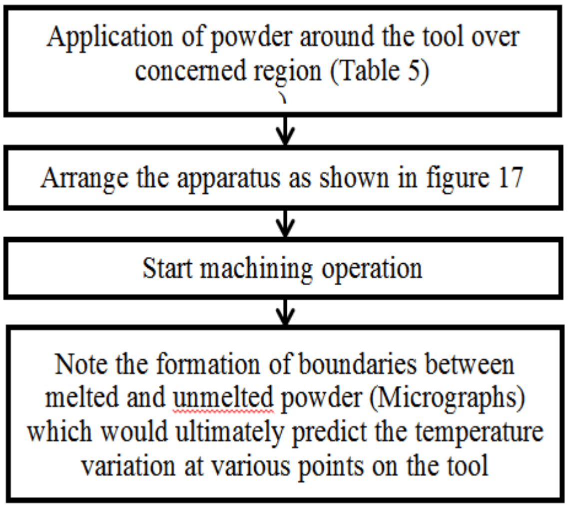


Figure 18. Process flow chart for fine powder technique

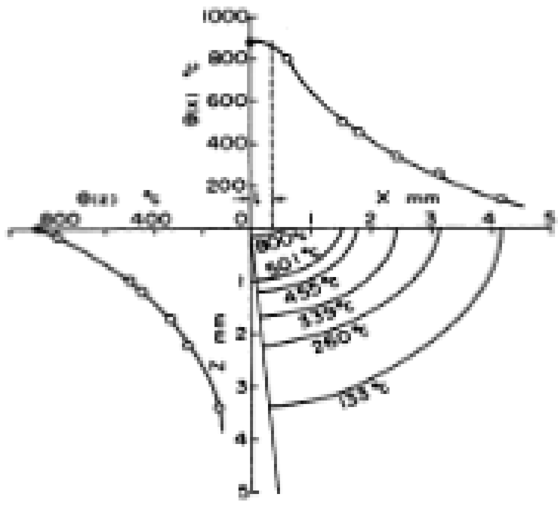


Figure 19. Temperature distribution contours along the rake face (*x*-direction) and the clearance face (*z*-direction) for carbide tool [81]

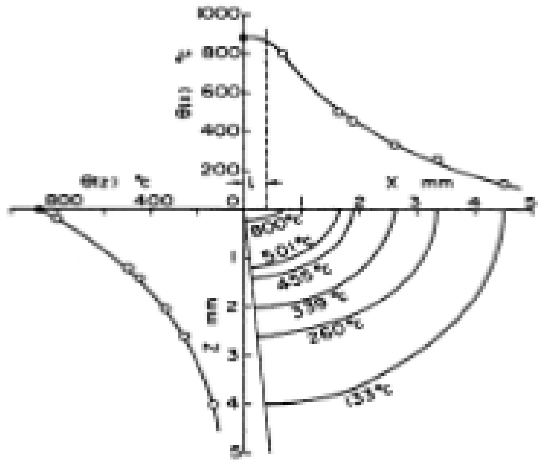


Figure. 20. Temperature distribution contours along the rake face (x-direction) and the clearance face (z-direction) for cermet tool [81]

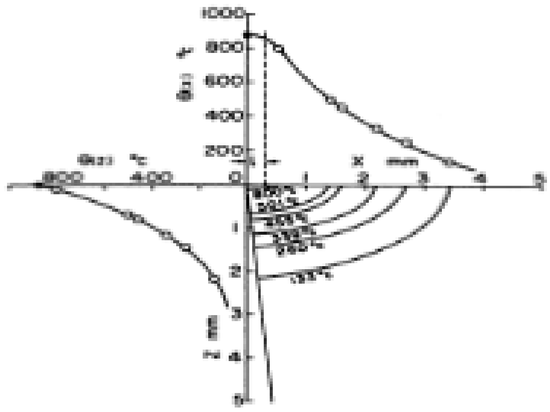


Figure 21. Temperature distribution contours along the rake face (*x*-direction) and the clearance face (*z*-direction) for ceramic tool [81]

2.7. Metallographic Methods

Wright and Trent [82] developed the technique for determining the temperature distribution at rake face of high speed steel (HSS) cutting tools. By observing the changes in microstructure of tool or by measuring the change in hardness of the tool, the temperature can be predicated. The results and charts obtained by Wright and Trent are explained in [82].

The major problems encountered in this method are: (i) it can only be used for HSS tool since it is difficult to study the microstructure change in other tools (carbide or ceramic); (ii) cutting is done at higher speeds, which results in rapid tool breakage; and (iii) microstructure change does not depend only on temperature variation and time of heating but also on other parameters like cooling period, etc. To overcome the problem, calibrations are required.

In spite of all these disadvantages, the method is capable of recording temperature in the range of 650–900^{0}C with an accuracy of ±25^{0}C.

3. Concluding Remarks

Having reviewed all the experimental techniques together, it has become clear that no technique is perfect and produces accurate results in all situations. Some methods are very complex, out of them only few produce good results; but such methods tend to be expensive. Some are very simple and economical but not very accurate. No particular technique can be applied in all situations. In conclusion, a comparative study of the merits and the demerits of all the technique, shown in Table 6, will be appropriate. Further, it is evident that a perfect technique, which is economical and implementable to all materials in all conditions, has not been yet developed.

Table 6. Comparative study of merits and demerits of various techniques

S.No.	Technique		Major Merits	Major Demerits	Remarks (if any)
1	Thermal paint		Simplest and economical	Not very accurate and prone to errors	Result verification by any other accurate enough technique is recommended
2	Thermocouple	Tool-work	Ease of experimental setup	For making observation at different point, setup is required to rearranged after stopping the machining	1. Calibration of tool-work piece pair is difficult 2. Limited transient response time
		Transverse	Capable of notifying temperature at various points without changing setup	Cannot be used for processes like grinding, drilling, milling, etc.	
		Embedded	Can be used for processes like grinding, drilling, milling, etc.	1.Temperature of surface cannot be measured directly 2. Destructive technique	
3	Pyrometer	Infrared radiation Optical Infrared radiation	1. Faster results 2. Can be used for any surface	1. Emissivity of body (under consideration) keeps on changing and hence affects the results 2. The complete isotherms cannot be plotted for every machining material	1. Photo cell is sensitive to change in ambient temperature, and IR 2.Destructive technique
4	Infrared photographic		1. Very fast response 2. Can be used in hazardous conditions	1. Requires preheating 2. Very expensive	Readings can be taken directly and long lasting
5	Fine powder		Economic	Not reliable , results are obtained in approximate temperature range	No need for calibration
6	Metallographic		Accuracy ±25^{0}C in the range of 650^{0}C to 900^{0}C	1.Can be used only for specific materials only (HSS) 2. High cutting speed 3. Rapid tool breakage	Requires calibration

References

[1] B. Thompson,“Count Rumford an inquiry concerning the source of heat which is excited by friction”, Philosophical Transactions of the Royal Society of London, 18: 1798, 278-287

[2] J. P. Joule,“Mechanical equivalent of heat”, Philosophical Transactions of the Royal Society of London 1850; 61-81

[3] G. I. Taylor, H. Quinney, “The latent energy remaining in a metal after cold working”, Proc. Roy. Soc.A, 143, 1934, 307-326

[4] F. W. Taylor, “On the art of cutting metals”, Transactions of ASME 1907; 28:31-248

[5] Marusich, Ortiz, “Modelling and simulation of high speed machining”, International Journal for Numerical Methods in Engineering, vol. 38, 1995, 3675-3694

[6] A. Y. Herchang, “Heat transfer & life of metal cutting tools in turning”, International Journal Heat and Mass Transfer, vol 41, no. 3, 1998, 613-623

[7] Ozel & Atlan, “Modeling of high speed machining process for predicting tool forces, stresses and temperatures using FEM simulations”, Proceedings of CIRP Institute, Workshop on Modeling in Machining operations, Atlanta USA, 1998.

[8] Ozel & Atlan, “Determination of work piece flow stress and friction at the chip tool contact for high speed cutting”, International Journal of Machine tools and Manufacture, vol 40, 2009, 133-152

[9] Gao & Sutherland, “FEM of orthogonal metal cutting process for qualitative understanding of the effects of crater wear on chip formation process”, Journal of Materials Processing Technology, 127, 2002, 309-324

[10] Shi et. al , “A finite Element study of the effect of friction in orthogonal metal cutting”, Finite Elements in Analysis & Design, 38, 2002, 863-883

[11] Grzesik, and Nieslony, “A computational approach to evaluate temperature and heat partition in machining with multilayer coated tools”, International Journal of Machine tools and Manufacture, 43, 2003, 1311-1317

[12] Chou, and Song, “Thermal modeling for white layer predictions in finish hard turning”, International Journal of Machine tools and Manufacture, 45, 2005, 481-495

[13] Ee et. al, “FEM of residual stresses in machining induced by cutting tool with finite edge radius”, Int. J. of Applied Thermal Engineering, 25, 2005, 2152-2168

[14] Astokov, “Effects of cutting feed, depth of cut, work piece (bore) diameter on tool wear rate”, Int. J. of AdvancedManufacturing Technology, 31, 2007, 631-40

[15] Movahhedy, “Simulation of chip formation in orthogonal metal cutting process: An ALE FEA approach”, Int. J. of Machining Science & Technology, 4(1), 2000, 15-42

[16] Dechjarern, “3D finite element investigations of the influence of tool rake angle on cutting performance”, Asian International Journal of Science and Technology in Production and Manufacturing, Vol. 1, No.2, 2008, 149-158

[17] Ramji, “Analysis of forces, roughness, wear and temperature in turning cast iron using cryo treated carbide inserts”, International Journal of Engineering Science and Technology Vol. 2(7), 2010,2521-2529

[18] Ozel et. al, “3D FEM of chip formation process for machining Inconel 718: comparison of FE software predictions”, Int. J. of Machining Science & Technology, 15, 2011, 21-46.

[19] A. Goyal, S. Dhiman, S. Tyagi, R. Sharma, “Studying methods of estimating heat generation at three different zones in metal cutting: A review of Analytical models”, International Journal of Engineering Trends and Technology, vol 8 (10), 2014, 532-45

[20] Schallbroach H, Long M. “Measurement of cutting temperature using temperature-indicating paints. Journal of the Association of German Engineers 87, 1943;15-9.

[21] E. Bickel, W. Widmer “Die Temperaturenan der Werkzeugschneide” Zurich, Switzerland: Industrielle Organization, 1954

[22] Tristan Lalanne and Christine Lempereur, “Color recognition with a camera: A supervised algorith for classification” Office National d'Etudeset de RecherchesAcrospatiales Centre d'Etudes et de Recherches de Toulouse.

[23] K. Okushima,R. Shimoda,“The cutting temperature”, Bull of JSME 1957;23:73–7.

[24] S. Rossetto, U. Koch,“An investigation of temperature distribution on tool flank surface”. Annals of CIRP 1971;19:551–7.

[25] Uchida et. al,, “Observation of spin seeback effect”, Macmilan publishers, vol 455, 2008, 778-818

[26] G. Barrow, ANN, CIRP 22,1973, 203-211

[27] Stephenson, “Tool – work thermocouple temperature measurements – theory and implementation issues” , J. of Manufacturing Science & Engineering, 115(4), 2008, 432-437

[28] M. C. Shaw, Metal cutting principles, Oxford University press, Londan, 1984

[29] L.B. Abhang and M. Hameedullah,“Chip-tool interface temperature prediction model for turning process”, International Journal of Engineering Science and Technology Vol. 2(4), 2010, 382-393

[30] K. J. Trigger, Progress report No.1, on chip-tool interface temperature Trans.ASME, 70, 1098, 91-98

[31] W. Grzesik,“Experimental investigation of the cutting temperature when turning with coated Index able inserts”, Int.J, of Machine tools and manufacture, 39, 1999, 355-369

[32] S.K. Choudhary, G.Bartarya, “Role of temperature and surface finish in predicting tool wear using neural network and design of experiments” Int. J.of machine tools and manufacture, 43, 2003, 747-753

[33] M. Federico, AheiroReginalot, Coelho, Lincdnc, Brandao, “Turning hardened steel using coated carbide at high cutting speeds” J.of the Braz.soc.OfMech.sci.and Engg, vol.xxx.no.2,2008, 1109

[34]B.Fnides, M.A. Yallese, H, Aouici, "Hard turning of hot work steel AISI H11: Evaluation of cutting pressure, resulting force and temperature", ISSN1392-1207, Mecanika, 2008.Nr.4 (72).

[35]H. Ay, W. J. Yang, "Heat transfer and life of metal cutting tools in turning", Int,J. Heat and mass transfer, 41, 1998,613-623

[36]G. Arndt, R. H. Brown, "On the temperature distribution in orthogonal machining", Int J Mach Tool Des Res,7, 1967, 39–53

[37]H. Ay, W. J. Yang, "Life of metal cutting tools in turning", Int. J. Heat Mass Transf., vol 41 (3), 1998, 613–623

[38]T. Kitagawa, A. Kubo, K. Maekawa, "Wear of cutting tools in high-speed machining of Inconel 718 and Ti–6Al–6V–2Sn", Wear, vol 202 (2), 1997, 142–148

[39]D. O'Sullivan, M. Cotterell, "Temperature measurement in single point turning", J. Mater. Process. Technol., vol 118 (1–3), 2001, 301– 308

[40]X. J. Ren, Q.X. Yang, R.D. James , L. Wang, "Cutting temperatures in hard turning chromium hardfacings with PCBN tooling", Journal of Materials Processing Technology, vol 147, 2004, 38–44

[41]A.Y.C. Nee, A.O. Tay, "On the measurement of surface grinding temperature", International Journal of Machine Tool Design and Research, vol 21 (34), 1981, 279–291

[42]W.B. Rowe, S.C. E. Black, B. Mills, "Temperature control in CBN grinding", The International Journal of Advanced Manufacturing Technology, vol 12, 1996, 387–392

[43]A. D. Batako, W. B. Rowe, M. N. Morgan, "Temperature measurement in high efficiency deep grinding", International Journal of Machine Tools and Manu facture, vol 45, 2005, 1231–1245

[44]A. Lefebvre, P. Vieville, P. Lipinski, C. Lescalier, "Numerical analysis of grinding temperature measurement by the foil/workpiece thermocouple method", International Journal of Machine Tools & Manufacture, vol 46, 2006, 1716–1726

[45]F.Z. Fang, L.C. Lee, X.D. Liu, "Mean flank temperature measurement in high speed dry cutting of magnesium alloy", Journal of Materials Processing Technology, vol 167, 2005, 119–123

[46]E.F. Smart, E.M. Trent, "Temperature distribution in tools used for cutting iron, titanium and nickel", Int. J. Prod. Res., vol 13 (3), 1975, 265–290

[47]S. C E. Black, W. B. Rowe, H. S. Qi, B. Mills, "Temperature measurement in grinding", Proceedings of 31st International MATADOR Conference, Manchester, April 1995, 409-13

[48]Dewes et al., "Temperature measurement when high speed machining hardened mould/die steel", Journal of Materials Processing Technology, Vol. 92-93, 1992, 293-301

[49]J. Shinozuka T. Obikawa T, "Development of Cutting Tools with Built-in Thin Film Thermocouples", Key Eng. Mater., vol 257–258, 2004, 547–552

[50]A. Basti, T. Obikawa, J. Shinozuka, "Tools with Built-in thin film thermocouple sensors for monitoring cutting temperature", Int. J.Mach. Tools Manuf., vol 47, 2007, 793–798

[51]K. Weinert, W. Tillmann, N. Hammer, C. Kempmann, E. Vogli, "Tool coatings as thermocouples for the monitoring of temperatures in turning processes", Adv. Eng. Mater., vol 8, 2006, 1007–1010

[52]D. Biermann, K. Pantke, E. Vogli, W. Tillmann, "Toolcoatings as thermocouple for chipping", In: Palmer, M. (Ed.), Proceedings of the TMS. San Francisco, USA, 2010, 389–393

[53]A.B. Chattopadhyay, "Cutting temperature causes, effects, assessment and control" MHRD NEPTEL Manufacturing Science II, Lecture 11, IIT Kharagpur India Version 2, Page 9

[54]S. C. Chou, K. D. Robertson, J. H. Rainey, "The effect of strain rate and heat developed during deformation on the stress-strain curve of plastics", Experimental mechanics, 13, 1973, 422-432

[55]D. Rittel,"Transient temperature measurement using embedded thermocouples, Int J. of Experimental Mechanics, Vol. 38 (2), 1998, pp 73-78

[56]D. L. Rall, W. H. Giedt,"Heat transfer to, and temperature distribution in, a metal cutting tool", Trans ASME, 78:1956, 1507–1515

[57]A. H. Qureshi, F. Koenigsberger, "An investigation into the problem of measuring the temperature distribution on the rake face of a cutting tool". Annals of CIRP 14, 1966, 189–99

[58]K. J. Kusters, "Das temperaturfeld in drehmeissel (The temperatue field in the cutting Edge of a cutting tool), Essen, Germany: Verlag W. Girardet, 1954.

[59]G. Boothroyd,"Photographic techniques for the determination of metal cutting temperatures" Brit J of Appl Physics,12:1961, 238-242

[60]A. B. Chattopadhyay, "Cutting temperature causes, effects, assessment and control",MHRD NEPTEL Manufacturing Science II, Lecture 11, IIT KharagpurIndia, Version 2, Page 11 accessed on 15 Dec 2012

[61]F. Schwerd,"Ueber die Bestimmung des temperatur-feldes beim Spanablauf (Determination of the temperature distribution during cutting)", Z VDI,9, 1993, 211

[62]G. Kraemer,"Neitrag zur Erkenntnis der beim Drehen auftretended Temperaturen und deren Messung mit einem Gesamtstrahlungs-Empfanger (Neitrag to the knowledge of auftretended when turning temperatures and their measurement with a total radiation-sempfanger) ", Dissertation, Hannover, 1936

[63]E. Lenz, "Ein Beitrag zur Messung der Schnit-temperatur beim Drehen mit keramischen Schneid-stoffen Maschinenmarkt (A contribution to the measurement of the cutting temperature when turning with ceramic cutting materials. Machinery)" 1960;28:20

[64]J. E. Mayer, M. C. Shaw, "Grinding temperatures" Lubrication Engineering J. of ASLE, 1957

[65]G. S. Reichenbach, "Experimental measurement of metal cutting temperature distribution" Trans ASME 80:1958, 525

[66]B. T. Chao, H. L. Li, K. J. Trigger, "An experimental measurement of metal cutting temperature distribution", Trans ASME , 83, 1961,496–504

[67] E. Lenz, “Ein Beitrag zur Messung der schnittemperatur beim Drehen mit keramischen Schneidstoffen Maschinenmarkt (A contribution to the measurement of the cutting temperature when turning with ceramic cutting materials. Machinery) ” 28:20, 1960

[68] E. Lenz, “Der Einfluss der Schnittempertur auf die standzeit der keramischen Schneidstoffen. Maschinen-markt (The influence of Schnittempertur on the tool life of the ceramic cutting materials. Machinery) ”28:30, 1963

[69] E. Lenz,“Die Temperaturverteilungan der Spanunter-seite in der Kontaktzone Span Wekzeug (The temperature distribution on the clamping base in the contact zone tension) ” Wekstattstechnik, 54:60, 1964

[70] Lenz E. “Die Temperaturverteilung in der Kontakt-zone Spanwekzeug beim Drehen von Stahl mit Hartmetall-Werkzeugen (The temperature distribution in the contact zone chip-Wek tool steel turning with carbide tools)”, Annals of CIRP, 14 (1966).

[71] M. Y. Friedman, E. Lenz E,“Determination of temperature field on upper chip surface”. Annals of CIRP, 19, 1971, 395–398

[72] O. D. Prins, “The influence of wear on the temperature distribution at the rake face”, Annals of CIRP,19, 1971, 579–584”

[73] T. Ueda, A. Hosokawa, A. Yamamoto, Studies on temperature of abrasive grains in grinding — application of infrared radiation pyrometer”, Trans ASME, J of Engg for Ind, 107, 1985, 127–133

[74] T. Ueda, K. Yamada, T. Sugita, “Measurement of grinding temperature of ceramics using infrared radiation pyrometer with optical fiber”, Trans ASME, J of Engg for Ind,114, 1992, 317–322

[75] T. Ueda, K. Kanazawa, H. Tanaka, Torli A, T. Sugita, “Measurement of grinding temperature of active grains using infrared radiation pyrometer with optical fiber”, Annals of CIRP, 42(1), 1993, 405–418

[76] T. Ueda, M. Sato, K. Nakayama,“The temperature of a single crystal diamond tool in turning”, Annals of CIRP,47(1), 1998, 41–44.

[77] R. C. Parker, P. R. Marshall,“The measurement of the temperature of sliding surfaces with particular reference to railway brake blocks”, Proc of the I Mech E (Lon),158, 1948,209–229

[78] G. Boothroyd, “Photographic techniques for the determination of metal cutting temperatures”, Brit J of Appl Physics, 12, 1961,238–242

[79] G. Boothroyd, “Temperatures in orthogonal metal cutting”. Proc I Mech E (Lon), 177, 1963, 789–810

[80] S. Jeelani, “Measurement of temperature distribution in machining using IR photography”, Wear, 68, 1981, 191–202

[81] S. Kato, K. Yamaguchi, Y. Watanabe, Y. Hiraiwa,“Measurement of temperature distribution within tool using powders of constant melting point”, Trans ASME, J of Engg for Ind, 108, 1876, 607–613

[82] P. K. Wright,E. M. Trent, “Metallographic methods of determining temperature gradients in cutting tools”, .J Iron and Steel Institute,211, 1973, 364–388

JJMIE

Volume 8 Number 2, April. 2014
ISSN 1995-6665
Pages 94 - 101

Jordan Journal of Mechanical and Industrial Engineering

Examining Factors that Affect Passenger's Overall Satisfaction and Loyalty: Evidence from Jordan Airport

Abbas Al-Refaie[1*], Nour Bata[2], Diana Eteiwi[2], and Issam Jalham[1]

[1] *Department of Industrial Engineering, The University of Jordan, Amman 11942, Jordan.*
[2] *Master Graduate, Department of Industrial Engineering, The University of Jordan, Amman 11942, Jordan.*

Abstract

This paper aims at investigating the effects of service quality, satisfaction with the service recovery, value, image, and price on passenger's overall satisfaction and loyalty. Three models are developed then analyzed. Model I studies the effect of in-flight services, flight availability, reservation and ticketing, airport services, employee services, and satisfaction with the web site and e-services on passenger's satisfaction and loyalty. Model II aims at studying the effect of service recovery, price, value, and image on passenger's satisfaction and behavioral loyalty. Model III investigates the effect of in-flight services and reservation and ticketing, airport services and employee services, reliability and flight availability, image, and value on passenger's satisfaction and on cognitive loyalty. Using statistical analysis, model I showed that in-flight services, reservation and ticketing, flight availability, reliability, employee services, airport services and satisfaction with the web site and e-services affect the passenger's overall satisfaction and that the overall passenger satisfaction affects both the behavioral and the attitudinal loyalty. While Model II revealed that the service recovery, price, value, and image affect the passenger's satisfaction and behavioral loyalty. Finally, Model III showed that in-flight services and reservation and ticketing, airport services and employee services, reliability and flight availability, image, and value affect the passenger's overall satisfaction, and that the passenger's satisfaction, in return, affects the cognitive loyalty. In conclusion, the developed models shall provide important feedback to airlines decision-makers who are significant factors that can enhance the passenger's satisfaction and put the airline industry at a competitive edge.

Keywords: *Passenger Satisfaction, Loyalty; Structural Equation Modeling; Service Quality.*

1. Introduction

Air travel, driven by liberalization and globalization, remains the fastest-growing market. Focus on service quality is highly needed if the airlines aspire to improve their market share and further enhance their financial performance in domestic and international markets [1]. In a highly competitive circumstance, the provision of high quality service that fulfills the passengers' satisfaction is the core competitive advantage for an airline's profitability and sustained development. Theory suggests that increasing customer retention is a major key to the ability of a service provider to generate profits [2]. Therefore, it is an important issue to better understand the determinants affecting a customer's loyalty and the relationships between determinants. Further, it is commonly believed that a higher service quality can lead to a customer's higher overall satisfaction, and subsequently to positive behavioral intentions. The variables 'intention to repurchase the same airline service' and 'willingness to recommend it' has been used as indicators of post purchase behavior in other fields [3].

However, some studies have suggested that the measurement of passenger satisfaction should be used in conjunction with the measurement of perceived value, and perceived value may be a better predictor of repurchase intentions than the satisfaction or the quality. Hence, service quality, perceived value, and satisfaction all seem to be good predictors of repurchase intentions while the relationship between them is still unclear [4].

When modeling the passengers' decision-making process, the key variables considered in airlines include: service quality, passenger's satisfaction, perceived cost, perceived value, and image, satisfaction with service recovery, behavioral loyalty, attitudinal loyalty and cognitive loyalty [5]. Customer demand and expectations are altering in today's world. In the airline Industry, many airlines have lost track of the true needs of their passengers and are sticking to the outdated view of what airline service is all about. Generally, the goal of airlines is to develop services that attract passengers and keep them satisfied and loyal, reflecting their positive experience to others. In reality, keeping existing passengers is much cheaper than acquiring new ones.

* Corresponding author. e-mail: abbas.alrefai@ju.edu.jo.

Delivering a high quality service to passengers is important so that airlines can survive and strengthen their competitiveness [6,7]. Consequently, research related to service quality and customer satisfaction in the airline industry has been growing significantly [8]. Moreover, airports, apart from providing a range of facilities to airlines, are evolving into multifaceted hubs containing hotels, conference centers, duty free shops, and shopping malls for passengers comfort.

Structural equation modeling has been widely used for a statistical analysis in many managerial applications [9-12]. This research, therefore, aims at examining the factors that affect the passenger's overall satisfaction and loyalty in Jordanian airport using structural equation modeling. Three structural models are developed then analyzed to achieve this purpose.

The present paper is organized in the following sequence: The first section is the introduction; section two presents the key factors that affect the purchasing behavior; section three develops structural models then describes data collection. Section four presents the models analyses. Section five summarizes the conclusions and implications of the present paper.

2. Factors Affecting Passengers' Purchasing Behavior

Several factors are reported to have effects on the passengers' purchasing behavior [13,14]. These factors are presented in the following subsections.

2.1. Service Quality

Service quality is the consumers overall impression of the relative inferiority/superiority of the organization and its services [15]. Delivering a high service quality has been recognized as the most efficient way of ensuring that a company's offerings are uniquely positioned in a market filled with look-alike competitive offerings [16,17].

The concept of service quality as a comparison between customers’ expectations and the actual services performed has gained wide acceptance. The extent to which expectations and service performance are similar or different influences the extent to which customers are satisfied or dissatisfied. In the airline industry, delivering a high quality service to passengers is essential for airlines survival. Airline service quality is a significant driver of passenger’s satisfaction, passenger loyalty, and passenger’s choice of airline. Hence, the delivery of a high service quality becomes a marketing requirement as the competitive pressures on air carriers are on the rise. Airline service quality is different from services in other industries. Airlines carry passengers to the destination using aircraft, and passengers experience diverse intangible services from airlines, such as on-time performance, in-flight service, service frequency and so on. The measures of service quality include [6,18, 19]:

- In-flight service quality: it aims at improving safety, quality and cost effectiveness of the in-flight services for the benefit of member airlines, partners, and passengers.
- Reservation and ticketing: these enable passengers to pre-schedule flights for use at a later time. Reserving airline tickets gets passengers a good price and guarantees a seat on the flight one needs. Advance ticketing is required on almost all flights unless one wants to pay a higher price.
- Airport services by developing and maintaining standards and procedures for the handling of passengers at airports, including all forms and regulations.
- Employee services, which aims at establishing employee friendly policies and management practices, foster a healthy, productive rewarding work environment and offer administrative and consulting services to departments and employees.
- Reliability: it means the ability of a person or system to perform and maintain functions in routine circumstances, as well as hostile and unexpected circumstances.
- Customer satisfaction with the web site and e-services. More recently, the pervasive use of Internet in the airline business has created a digitalized market that improves the processes dealing with acquisition, management, and maintenance of customers. The trend towards disintermediation helps airlines bypass travel agents or other intermediaries to get closer to their customers and the internet to facilitate a two-way communication, online sales, e-tickets and a range of new technologies.

2.2. Customer Satisfaction

Satisfaction is an overall effective response to a perceived discrepancy between a prior expectation and a perceived performance after consumption [7]. It can be defined as the degree which one believes that an experience evokes positive feelings. Customer satisfaction is defined as a judgment made on the basis of a specific service encounter. It is a very important concept in marketing and it is the ultimate goal for service operations. Increasing the customer satisfaction leads to improved profits, lower marketing expenditures, and a positive word-of-mouth communication [20].

2.3. Corporate Image

Corporate image can be defined as perceptions of an organization reflected in the associations held in consumer memory [20]. A company with a good image is more likely to stand out in the marketplace because it draws both repeat customers and trial users. The image of the airlines is important in reflecting a distinctive competence in comparison with the competitors, making the airline's name, symbol, or identity distinctive with a corresponding appeal. A favorable image separates and distinguishes the company from its competitors. Thus, a favorable image of a specific airline can lead passengers to contemplate air travel.

2.4. Perceived Value and Loyalty

Perceived value is the consumer's overall assessment of the utility of a product (or service) based on perceptions of what is received and what is given. That is, perceived value is the remaining of what a consumer obtains subtracted from what he pays for. Further, there are three main streams in loyalty: behavioral, altitudinal, and cognitive. Oliver [21] mentioned that loyalty should be developed in a sequence of cognition affect conation pattern. He concluded that customers would first come in a stage called cognitive loyalty, in which customers became loyal in a sense of cognition on the basis of prior knowledge or belief on the brand. Then, after several usages or interactions, a favorable attitude toward the brand would be developed on the basis of accumulative satisfaction in the stage of affective loyalty. The next phase of developing loyalty is the cognitive stage in which customers would hold a strong commitment to the purchase intention, avoiding any persuasion from other alternatives. Therefore, the analysis of the true customer loyalty requires to assess customer's beliefs (cognition), affection (attitude) and repurchase action (behavior) simultaneously.

Service loyalty is defined as the willingness of a customer to consistently re-patronize the same service provider/service company, which maybe the first choice among alternatives, thereby complying with actual behavioral outcomes and attaching with favorable attitude and cognition, regardless of any situational influences and marketing efforts made to induce a behavior switching [18]. In reality, customers usually have two or three choices within any category from which they regularly buy. Therefore, the formation of service loyalty in this paper satisfies three conditions:

- The passengers having a strong desire for the service continuously or periodically.
- The passengers having freedom to choose their favorite service provider or service company.
- There are more than one service provider within the same service industry.

Various measures in terms of behavioral, attitudinal and cognitive attributes are used as measures of service loyalty; these include [22-24]:

- Repeat purchase behavior: this is one kind of "loyalty-prone" behavior showing a continual commitment to an entity.
- Word of mouth: this means recommending others to purchase through any common means. This indicator is important for assessing loyalty. Besides, the term "word-of-mouth" involves internal communication with service staff. So it is believed that loyal customers are likely to give positive feedback to the service company.
- Period of Usage: it represents the time interval in which the customer keeps a continuous consumption from a particular service provider. It is also a very common indicator for assessing loyalty because it can definitely reflect the real situation of a customer's consumption from the same service provider continuously and can especially emphasize the long-term characteristic of service loyalty.
- Repeat purchase intention basically refers to the extent of repeat purchase intention from the same service provider with affective commitment.
- Preference is the typical measure for the attitudinal dimension of service loyalty, as "true" loyalty can only be attained when the customer expresses a strong positive preference for and a high repeat patronage of an entity.
- Choice reduction behavior: this is a definite resultant behavior of loyalty, as customers with a great deal amount of strong loyalty would reduce the search motivation, and eventually forgo other alternatives, which reduces the competitive efforts on decision making.
- First-in-mind, consistent with choice reduction behavior: it is suggested that the extremely loyal customers will be ideally limited to only one choice that should be the first choice in mind. Therefore, a high level of service loyalty will lead customers to consider the service provider as the first in his/her mind.

2.5. Satisfaction with the Service Recovery and Price

In reality, airlines strive to deliver a superior service quality that enhances the value perceptions of airline services, which, in turn, leads to a customer satisfaction. To address service failures, airlines develop service recovery policies; such policies are meant to resolve customers' inquiries and complaints to recover their satisfaction and trust [23]. Service recovery comprises the actions that a service provider takes to respond to service failures and the process by which the firm attempts to rectify such failures.

On the other hand, understanding and predicting the influence of price on the willingness to purchase has been a fundamental interest of not only economists but also marketing researchers [25]. One aspect of price that influences the purchase decisions is fairness. Buyers' perception of a fair price has been considered a determinant of the consumers' willingness to buy and a reason for the consumers' resistance to buying. They showed that a price perceived to be ''high'' was judged unfair and led subjects to consider either leaving the store or, less likely, complaining. However, their research had two limitations. First, it used ''fair'' as a dependent measure, allowing subjects to interpret the term however they chose. Second, the study considered fairness in the narrow sense of being cheap only; what is here considered is ''economic fairness''. To understand how fairness affects price evaluations, it is necessary to understand the full meaning of fairness, considering its social and economic aspects. The price to be paid for a service determines, for the passenger, the level of quality to be demanded.

3. Proposed Models

Three models I to III are developed as follows:

3.1. Model I: Service Quality Model

This model is shown in Figure 1, which displays the hypothesized positive relationships between service quality represented by: In-flight services (IFS) & flight availability (FA), reservation and ticketing (R&T) & employee service (ES) & airport services (AS), reliability (RE), customer satisfaction with the web site and e-services (CSWS), with passenger satisfaction (PS) and with attitudinal loyalty (AL) & behavioral loyalty (BL). The hypotheses include:

H1: In-flight service has a positive effect on passenger satisfaction.

H2: Reservation and ticketing has a positive effect on passenger satisfaction.

H3: Airport service has a positive effect on passenger satisfaction.

H4: Employee service has a positive effect on passenger satisfaction.

H7: Customer satisfaction with the web site and e-service has a positive effect on passenger satisfaction.

H5: Reliability has a positive effect on passenger satisfaction.

H6: Flight availability has a positive effect on passenger satisfaction.

H8: passenger satisfaction has a positive effect on attitudinal loyalty.

H9: passenger satisfaction has a positive effect on behavioral loyalty.

3.2. Model II: Cognitive Loyalty Model

This model shows the hypothesized positive relationships among in-flight services & reservation and ticketing (IFS, R&T), airport services & employee services, reliability & flight availability (RE & FA), perceived value (PV), and image (IM) on overall passenger satisfaction and on cognitive loyalty (CL). The hypotheses involve:

H1: In-flight service has a positive effect on passenger satisfaction.

H2: Reservation and ticketing has a positive effect on passenger satisfaction.

H3: Airport service has a positive effect on passenger satisfaction.

H4: Employee service has a positive effect on passenger satisfaction.

H5: Reliability has a positive effect on passenger satisfaction.

H6: Flight availability and delay has a positive effect on passenger satisfaction.

H10: Passenger satisfaction has a positive effect on cognitive loyalty.

H11: Perceived value has a significant positive effect on cognitive loyalty.

H12: Perceived value has a significant positive effect on passenger satisfaction.

H14a: Service quality (In-flight-Reservation) has significant, positive effect on perceived value.

H14b: Service quality (Airport-Employee) has significant, positive effect on perceived value.

H14c: Service quality (Reliability-Flight available) significantly affect the perceived value.

H18: Image has a significant, positive effect on passenger satisfaction.

H19: Image has a significant, positive effect on perceived value.

H21: Image has a significant, positive effect on cognitive loyalty.

3.3. Model III: Service Recovery Model

This model investigates the relationship among service recovery (SR), price (PR), perceived value, image (IM), satisfaction with web services with overall passenger satisfaction with behavioral loyalty. Figure 3 depicts a graphical representation of Model III. The proposed hypotheses are:

H9: Passenger satisfaction has a positive effect on behavioral loyalty.

H12: Perceived value has a significant positive effect on passenger satisfaction.

H14: Perceived value has a significant positive effect on behavioral loyalty.

H15: Perceived value has a significant, positive effect on price.

H16: Price has a positive effect on passenger’s satisfaction.

H18: Image has a significant, positive effect on passenger satisfaction.

H19: Image has a significant, positive effect on perceived value.

H20: Image has a significant, positive effect on behavioral loyalty.

H23: Passenger perceptions of the airline’s service recovery performance are positively related to passenger satisfaction.

H24: Passenger perceptions of the airline’s service recovery performance are positively related to passenger's behavioral loyalty.

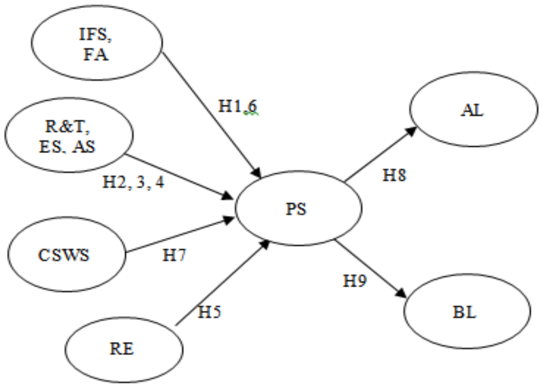


Figure 1: Structural model for service quality.

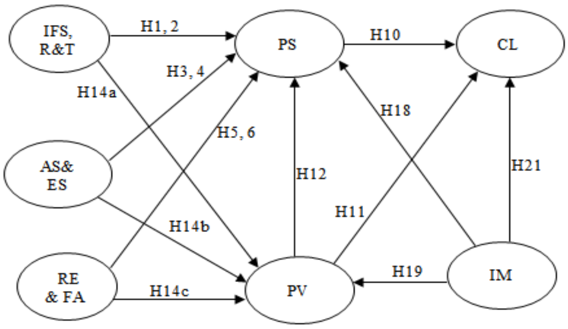


Figure 2: Structural model for cognitive loyalty.

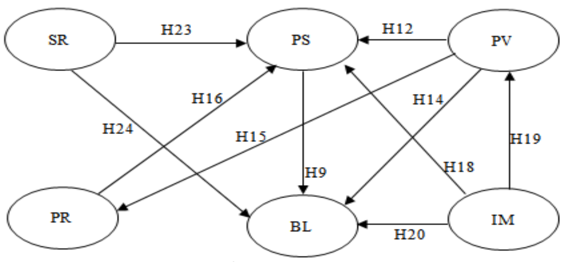


Figure 3: Structural model for service recovery.

3.4. Item Measures for Models' Variables

The questionnaire consists of the item measures of all models' variables and is composed of two parts; the first part consists of questions regarding the variables in the models. The scale used is a seven-point likert scale as a measure according to many previous studies that used this scale in surveys regarding service quality in airlines [5], ranging from 1= strongly disagree to 7= strongly agree. The second part consists of passenger's demographic parameters. The design of the questionnaire is based on a multiple item measurement scale. The measurement items are designed for the airline and the statements are measured on a seven point likert-type scale [19]. The questions in the questionnaire were based on a review of the literature and specific airline service contexts.

The first part of the questionnaire consists of the demographic parameters of the passengers collected as shown in Table 1. The second part contains the items measures for each variable as shown in Table 2. A Pilot study was conducted to see if any of the statements was difficult for subjects to understand and to check for the appropriateness of the items used in this paper. A number of samples of international passengers, who have recent travel experiences, were consulted in the pilot study. In addition, the questionnaire was first reviewed by airline experts and airline staff, who have airline experience. Based on the opinions of those experts and passengers, the final version of the questionnaire was designed. The survey instrument contained questions related to demographic parameters. Sample survey is the method of collecting and gathering information from a part of the population by using a structured questionnaire. In this model simple random sampling is used, which gives a known and equal nonzero chance of selection to each member of the population.

Table 1. Demographic parameters.

Demographic parameter	Item
Gender	Male Female
Age	15-30 31-45 46-60 60+
Occupation	This was specified according to the passenger
Education	Primary school Secondary University degree Other and please specify type
Nationality	This was specified according to the passenger
Class of travel	Business Economy
Airline of travel	This was specified according to the passenger
Frequent flyer member	Yes No

Table 2. Measures for models' variables.

Construct	Measure
Service quality	In-flight services
	Reservation and ticketing
	Airport services
	Employee services
	Reliability
	Flight availability
	Customer satisfaction with the web site and e-services
Overall passenger satisfaction	
Price	
Service recovery	
Image	
Value	
Behavioral loyalty	
Attitudinal loyalty	
Cognitive loyalty	

4. Models' Analyses and Results

4.1. Models' Analyses

Two statistical analyses are conducted on the three proposed structural models as follows:

4.1.1. Demographic Profile of the Respondents

The profile of the respondents is looked upon in terms of age, gender, educational attainment and airline of travel. Two hundred and sixty three surveys are collected. The majority (= 68 %) of the respondents were 15-30 years old. This indicates that most of the respondents were young adults. The number of the female respondents (= 48%) is close to that of the male respondents (51%). This shows a comparatively equal footing in terms of representation of gender in the effectiveness of overall satisfaction with and loyalty to the airline service quality. Finally, about 79% of all respondents are university graduates. These data illustrate the sufficiency of the respondents particularly in terms of education and skill to imply their satisfaction and loyalty in airline service quality.

4.1.2. Structural Analyses of the Models

Several statistical tests were employed to analyze the multicollinearity, consistency, and validity of the proposed models [26-28]. These tools are discussed as follows:

- Multicollinearity

Measures the degree by which items measure the same entity; a value of 0.9 or above for the inter-item correlations indicates the possibility that two or more items measure the same entity [29]. Inter-item correlations analyses for Model I, II, and III revealed that the multicollinearity type problems did not appear to be present.

- Test of Reliability

To assess reliability, internal consistency methods are widely used; generally alpha is used to assess internal consistency. A value of 0.6 or less generally indicates unsatisfactory consistency reliability [30,31]. The estimated alpha values for measures of Model I, II, and III are presented in Tables 3 to 5, respectively. Alpha results for model I and II have values of 0.6 or larger, except for the attitudinal and cognitive loyalty, which have values of 0.534 and 0.523, respectively. The overall alpha is equal to 0.934. For Model III, however, results show that the alpha values are larger than 0.6; except for the price which has a value of 0.4. It is concluded that all the three models achieved internal consistency.

- Model Fitness

Confirmatory factor analysis (CFA) is used to test the validity of the measurement model [32]. Generally, in structural equation modeling, the fit of the model using chi-square is not always as straight forward as the assessment of the fit of the model, because the chi-square value is not independent of the sample size. Hence, various kinds of fit indices, that are supposedly independent of sample size, were developed [33]. Among various fit indices, the minimum is achieved with a chi-square of 939 and degrees of freedom (DF) of 610 and p value level less than 0.0001, which is less than the p value of 0.001. In general, if the ratio between the chi-square goodness of the fit measure and the degrees of freedom is less than two, the model is accepted [34]. In this model, the ratio is 1.54, which is less than two. As for the root mean square error of approximation (RMSEA), the recommended RMSEA is 0.09. For model **I**, the RMSEA is 0.08 acceptable. The goodness of fit index (GFI) is 0.89. For Model II, the chi-square is 320.6 , degrees of freedom are (DF= 227) and the p value is 0.0001. The ratio is 1.41. The RMSEA and GFI values are 0.91 and 0.06, respectively. For Model III, the ratio of chi-square divided by DF is 1.24. The values of RMSEA and GFI are 0.86 and 0.08, respectively. The estimated values of fit indices indicate the validity of the proposed models. Hence, conclusions can be drawn from the hypotheses results.

Table 3. Cronbach's alpha values for Model I.

Variable	Alpha
In flight services and flight availability	0.635
Reservation & ticketing, and airport & employee services	0.635
Reliability	0.763
Web and e-services	0.784
Overall passenger satisfaction	0.714
Behavioral loyalty	0.641
Attitudinal loyalty	0.534

Table 4. Cronbach's alpha values for Model II.

Variable	Alpha
In flight and reservation and ticketing	0.765
Airport and employee services	0.796
Reliability and flight availability	0.823
Overall passenger satisfaction	0.746
Value	0.695
Image	0.692
Cognitive loyalty	0.523

Table 5. Cronbach's alpha values for Model III.

Variable	Alpha
Overall passenger satisfaction and satisfaction with Web and e-services	0.82
Service recovery	0.68
Price	0.40
Value	0.60
Image	0.65
Behavioral loyalty	0.64

4.2. Results of Models' Hypotheses Testing

Tables 6 to 8 display the results of hypotheses testing for Models I, II, and III, respectively.

Table 6. Results of hypothesis testing for Model I.

Hypothesis	P value	Result
H5	< 0.001	Accepted
H7	< 0.001	Accepted
H2, H3, H4	< 0.001	Accepted
H1, H6	< 0.001	Accepted
H8	< 0.001	Accepted
H9	< 0.001	Accepted

Table 7. Results of hypothesis testing for Model II.

Hypothesis	P value	Estimate
H1,H2	0.050	Almost Accepted
H3,H4	0.001	Accepted
H5,H6	0.547	Rejected
H14a	0.033	Almost Accepted
H14b	0.003	Accepted
H14c	0.045	Almost Accepted
H12	0.001	Accepted
H18	0.001	Accepted
H19	0.079	Almost Accepted
H11	0.111	Rejected
H21	0.0001	Accepted
H10	0.0001	Accepted

Table 8. Results of hypothesis testing for Model III.

Hypothesis	P value	Result
H19	< 0.001	Accepted
H15	< 0.001	Accepted
H16	< 0.001	Accepted
H23	< 0.001	Accepted
H18	< 0.001	Accepted
H12	< 0.001	Accepted
H9	< 0.001	Accepted
H14	0.762	Rejected
H24	0.0008	Accepted
H20	< 0.001	Accepted

From Tables 6 to 8, the following results are obtained:

- From Table 6 for the results of Model **I**, all the hypotheses are accepted, because the *p* values are less than 0.0001. Consequently, it is concluded that in-flight services, reservation and ticketing, flight availability, reliability, employee services, airport services and satisfaction with the web site and e-services positively affect the passenger's overall satisfaction. Moreover, the passenger's satisfaction affects both the behavioral and the attitudinal loyalty.
- For the results of the hypotheses testing of Model II shown in Table 7, the effect of in-flight services, reservation and ticketing, in-flight availability, and reliability have marginal effects on the passenger's overall satisfaction. Moreover, the image has a marginal effect on the perceived value. It is concluded that in-flight services and reservation and ticketing, airport services and employee services, reliability and flight availability, affect passenger's satisfaction; while value, and image affect the passenger's overall satisfaction. In addition, overall passenger satisfaction affects the cognitive loyalty; while airport service, employee service, perceived value, and image have a positive effect on passenger's satisfaction. Moreover, passenger satisfaction and image have a positive effect on cognitive loyalty. Also, service quality (Airport-Employee) has a significant, positive effect on the perceived value. Finally, reliability, flight availability have negligible effects on passenger satisfaction, and the perceived value has a little effect on cognitive loyalty.
- In Table 8 for Model III, the image has significant positive effects on passenger's satisfaction, perceived value, and behavioral loyalty. Moreover, perceived value and price have significant positive effects on the passenger's satisfaction. Further, passenger perceptions of the airline's service recovery performance are positively related to passenger satisfaction and behavioral loyalty. Furthermore, passenger satisfaction has a positive effect on behavioral loyalty, and the perceived value has a significant positive effect on price. However, the perceived value has a significant positive effect on the behavioral loyalty.

5. Conclusion and Implications

The present paper studied the effects of service quality, satisfaction with the service recovery, value, image, and price on the passenger's overall satisfaction and loyalty. Three models were developed then analyzed using structural equation modeling. Data were collected from passengers in a Jordanian airport. The results of Model **I** suggest that airlines should realize that improvements in these dimensions of service will enhance passengers' repurchase intentions and their preference to the airline; thus, airlines should allocate the appropriate resources across these service dimensions and airlines should constantly keep upgrading these service dimensions to the highest standards that will maintain the passenger's satisfaction.

The results of Model II recommend that airlines should realize that the improvements in these service dimensions will enhance passengers' repurchase intentions and their devotion to the airline as their number one choice among the other airlines available; thus, airlines should allocate the appropriate resources across these service dimensions and airlines should constantly keep upgrading these service dimensions to the highest standards, which will, in turn, maintain the passenger's satisfaction and keep the airline as the number-one choice for the passengers among the other competitors in the market.

Finally, the results of Model **III** showed that service providers can influence consumers' emotions through their efforts to recover the service. Specifically, to reduce negative emotions and consequently raise the service recovery, airlines should see the presence of negative emotions as a sign of the need to improve the service recovery process.

In conclusion, this paper has important implications regarding the passenger's satisfaction. First, the inference for airlines is to continue to emphasize building a favorable image as a means of improving passengers' repurchase rate and recommending them to other passenger. Second, airlines should observe pricing and recognize the perceived value as a contributing factor to the airline's image and the passengers' behavioral intentions. Finally, airlines should understand the trade-offs, which are required between service quality and ticket prices, before they develop marketing strategies, and then they should enhance the passengers' value perceptions.

References

[1] V. Dutt, M. Khan, "Customer perceptions, expectations and Gaps in service quality: An imperical study of civil aviation industry in India". Journal of Service Marketing, Vol. 12, No. 1, 2005, 7-22.

[2] V.A. Zeithaml, L.L. Berry, A. Parasuraman, "The behavioural consequences of service quality". Journal of Marketing Management, Vol. 60, 1996, 31-46.

[3] J.E. Bigne, M.I. Sanchez, J. Sanchez, "Tourism image, evaluation variables and after purchase behaviour: Inter-relationship". Tourism Management, Vol. 22, 2001, 607-716.

[4] C. Chen, "Investigating structural relationships between service quality, perceived value, satisfaction, and behavioral intentions for air passengers: Evidence from Taiwan". Transportation Research Part A, Vol. 42, 2008, 709-717.

[5] J. Park, "Passenger perceptions of service quality: Korean and Australian case studies". Journal of Air Transport Management, Vol. 13, 2007, 238-242.

[6] K. Balcombe, I. Fraser, L. Harris, "Consumer willingness to pay for in-flight service and comfort levels: A choice experiment". Journal of Air Transport Management, Vol. 15, 2009, 221-226.

[7] M. Brady, J. Cronin, T. Hult, "Assessing the effects of quality, value, and customer satisfaction on consumer behavioral intentions in service environments". Journal of Retailing, Vol. 76, No. 2, 2009, 193-218.

[8] K.L. Siam, H.C. Koh, S. Shetty, "Some potential issues of service quality reporting for airlines". Journal of Air Transport Management, Vol. 12, 2006, 293-299.

[9] A. Al-Refaie, B. Hanayneh, "Influences of TPM, TQM, Six sigma practices on performance in Jordan". International Journal of Productivity and Quality Management, Vol. 13, No. 2, 2014, 219-234.

[10] A. Al-Refaie, M-H. Li, J.H. Ko, "Factors Affecting Customer Linking Capabilities and Customer Satisfaction in CRM: Evidence from Jordanian Hotels". International Journal of Customer Relationship Marketing and Management, Vol. 3, No. 4, 2012, 16-30.

[11] A. Al-Refaie, J.H. Ko, M-H. Li, "Examining the factors that affect tourists' satisfaction, loyalty, WOM and intention to return using SEM: Evidence from Jordan". International Journal of Leisure and Tourism Marketing, Vol. 3, No. 2, 2012, 179-197.

[12] A. Al-Refaie, I.S. Jalham, M-H. Li, "Factors influencing the repurchase intention and customer satisfaction: A case of Jordanian telecom companies". International Journal of Productivity and Quality Management, Vol. 10, No. 3, 2012, 374-387.

[13] R.J. Brodie, G.J. Brush, J.R.M. Whittome, "Investigating the service brand: A customer value perspective". Journal of Business Research, Vol. 62, 2009, 345-355.

[14] J. Park, R. Robertson, C. Wu, "The effect of airline service quality on passengers' behavioral intentions: A Korean case study". Journal of Air Transport Management, Vol. 10, 2004, 435-439.

[15] Bitner M.J., Hubbert A.R. Encounter satisfaction versus overall satisfaction versus service quality: the consumer's voice. in Rust, R.T. and Oliver, R.L. (Eds), Service Quality: New Directions in Theory and Practice, Sage Publications, Thousand Oaks, CA; 1994.

[16] C. Chen, D. Hensher, R. Jou, C. Kuo, S. Lam "The effect of service quality and price on international airline competition". Transportation Research Part E, Vol. 44, 2008, 580-592.

[17] A. Parasuraman, V.A. Zeithaml, L. Berry, "Refinement and reassessment of the SERVQUAL scale". Journal of Retailing, Vol. 67, No. 4, 1991, 420-450.

[18] Y. Chang, F. Chen, "Relational benefits, switching barriers and loyalty: A study of airline customers in Taiwan". Journal of Air Transport Management, Vol. 13, 2007, 104-109.

[19] J. Park, R. Robertson, C. Wu, "The effects of individual dimensions of airline service quality: Findings from Australian domestic air passengers". Journal of Hospitality and Tourism Management, Vol. 13, No. 2, 2006, 161-176.

[20] B.J. Babin, F. Lai, M. Griffen, "How quality, value, image, and satisfaction create loyalty at a Chinese telecom". Journal of Business Research, Vol. 62, 2009, 980-986.

[21] R.L. Oliver, "Whence customer loyalty?". Journal of Marketing, Vol. 63, 1999, 33-44.

[22] J. Cheng, F. Chen, Y. Chang, "Airline relationship quality: An examination of Taiwanese passengers". Tourism Management, Vol. 29, 2006, 487-499.

[23] H. Chou, J. Lu, P. Ling, "Investigating passengers' intentions to use technology-based self-check-in services". Transportation Research Part E, Vol. 45, 2009, 345-356.

[24] H. Koh, S. Shetty, K. Sim, "Potential issues of service quality reporting for airlines". Journal of Air Transport Management, Vol. 12, 2006, 293-299.

[25] R. Jou, S. Lam, D.A. Hensher, C. Chen, C. Kuo, "The effect of service quality and price on international airline competition". Transportation Research Part E, Vol. 44, 2008, 580-592.

[26] A. Al-Refaie, O. Ghnaimat, M-H. Li, "Effects of ISO 9001 certification and KAAE on performance of Jordanian firms". Jordan Journal of Mechanical and Industrial Engineering, Vol. 6, No. 1, 2012, 45-53.

[27] A. Al-Refaie, M-H. Li, I. Jalham, "Factors Influencing the Repurchase and Customer Satisfaction: A Case of Jordanian Telecom Companies". International Journal of Productivity and Quality Management, Vol. 10, No. 3, 2012, 374-387.

[28] A. Al-Refaie, O. Ghnaimat, J-H. Ko, "The effects of quality management practices on customer satisfaction and innovation: A perspective from Jordan". International Journal of Productivity and Quality Management, Vol. 8, No. 4, 2011, 398-415.

[29] A. Al-Refaie, "A structural model to investigate factors affect patient satisfaction and revisit intention in Jordanian hospitals". International Journal of Artificial Life Research, Vol. 2, No. 4, 2011, 43-56.

[30] A. Al-Refaie, "Factors affect companies' safety performance in Jordan using structural equation modeling". Safety Science, Vol. 57, 2013, 169–178.

[31] A. Al-Refaie, R. Foud, D. Eteiwi, "Examining factors affect passenger's satisfaction and loyalty: A comparative analysis from Jordan airport". Advances in Information Sciences and Service Sciences-An International Journal of Research and Innovation, Vol. 5, No. 3, 2013, 641-650.

[32] Hair J.F.Jr., Anderson R.E., Tatham R.L., Black W.C. Multivariate data analysis. 5th ed. New Jersey: Prentice Hall; 1998.

[33] Hoyle R.H. The structural equation modeling approach: Basic concepts and fundament al issues. In Structural equation modeling: Concepts, issues, and applications, R. H. Hoyle (editor). Thousand Oaks, CA: Sage Publications, Inc., pp. 1-15; 1995.

[34] Byrne B.M. Structural Equation Modeling with AMOS: Basic Concepts, Applications, and Programming. London: Mahvah; 2001.

JJMIE
Volume 8 Number 2, April. 2014
ISSN 1995-6665
Pages 102 - 118
Jordan Journal of Mechanical and Industrial Engineering

Developing an ISO27001 Information Security Management System for an Educational Institute: Hashemite University as a Case Study

Awni Itradat [*], Sari Sultan, Maram Al-Junaidi, Rawa'a Qaffaf, Feda'a Mashal, and Fatima Daas

Department of Computer Engineering, Hashemite University, Zarqa 13115, Jordan

Abstract

Information is becoming one of the most important assets for almost every organization. Information systems are essential for every organization to access its information. However, these systems need to be secure in terms of confidentiality, integrity, and availability of the information. Information security comes as a magical solution for these requirements where a security audit of the system is developed to define and prioritize the risks that face information asset of the information system. So, risk assessment is applied to identify the risks and their impact on the system. Risk assessment is developed based on the vulnerability assessment, targeting specific information assets. Securing the information systems is the concern of the Information Security Management System ISMS adopted by the organization. Universities information systems are critical systems due to the rapid growth demand of students enrolling in universities in different programs, which will pay a higher level of complexity of these information systems. In this paper, an evaluation of the information security level at the Jordanian universities has been developed by launching a case study targeting the Hashemite University (HU). The case study focuses on analyzing the risks that faces HU information systems from two different perspectives (organizational and technical risks) by applying vulnerabilities assessment and penetration testing, finally organized into a risk assessment plan. During the case study, an ISO/IEC 27001:2005 ISMS has been developed in order to eliminate the risks that face the HU information systems. The ISMS (Information Security Management System) provides the required policies and controls in order to minimize the identified risks and to facilitate examining and enhancing the information security experience of HU.

Keywords: *Information Security Management System ISMS, Risk assessment, Vulnerability Assessment, ISO/IEC 27001.*

1. Introduction

Information is becoming one of the most important assets in the 21st century for almost every organization. Vulnerability assessment comes as a solution for identifying the security holes in (a) specific information system(s), by identifying the threats that pose a serious exposure to the organization's assets, which leads to identifying unattended threats and quantifying the reactive measures. A unique set of testing processes, tools, and techniques are followed to detect and identify vulnerabilities in information systems. The penetration testing goes beyond the level of identifying vulnerabilities and hooks into the process of exploitation, privilege escalation, and maintaining access to the information system, showing the real value of the threat and how it can affect the information system. Vulnerability assessment and penetration testing are not a good indemnity for a secure information system. Since most of the highest impact security breaches come from inside the organization, there should be a control mechanism for the information system users/implementer to protect the system from being compromised internally, this could extend also to insuring that the information system business continuity do not exclusively depend on a specific individual existence which could lead to a serious system halt/crash based on the availability of specific personnel. Information Security Management Systems (ISMS) provide a complete solution for a better information security experience by providing the needed policies, tools, and procedures for enhancing and maintaining a secured information system.

Recently, most of the Jordanian universities (for example, the Hashemite University (HU)), have been facing a rapid growth demand of students enrolling in its programs, both undergraduate and graduate. As the number of student's increases, the organization and maintainability of its information, which is one of the most important assets affecting the business continuity of the

[*] Corresponding author. e-mail: itradat@hu.edu.jo.

universities, are becoming more and more complicated due to huge amount of paper work to do as well as the hard copy that should be stored and retrieved regularly. Moreover, hard copies must be stored in a secure manner to avoid their sensitive content from being disclosed, tampered, modified, or disrupted, which could lead to the destruction of organization's reputation. This might lead to damaging the credibility of the organization concerning the protection of its own information properly or even to skepticism about the legitimacy of the organization's information as well as the validity of its graduate student's certificates.

The Hashemite University is one of the highly reputable universities in The Hashemite kingdom of Jordan (HKJ). The HU Information, Communication and E-learning Center (ICET) has been working closely with different HU departments since 1996 in order to computerize its operations such as (student's registration, student's exams, students/employees portals, mailing services, and financials). Computerizing manual operations and some of the paper work comes as a magical solution by using computer-based applications to complete complex, time-consuming, redundant operations in order to organize and maintain student's information efficiently time-wise and effort-wise. These computerized operations must insure information Confidentiality, Integrity, and Availability, unless they can be very easily disclosed, tampered, modified, or disrupted.

Computerized systems are usually built by adopting one of the common solutions such as Microsoft, Oracle, or others. Security holes in these solutions would make the computerized system weak and easy to penetrate. Moreover, lack of awareness about the usage and the configuration for a specific solution leads to more dangerous vulnerabilities in the resulting system. For example, allowing default login credentials on a specific solution allows unauthorized users to get authenticated to a specific system using default login credentials.

In this paper, an evaluation of the information security level at the Jordanian universities has been developed by launching a case study targeting HU. The case study focuses on analyzing the risks that face HU information systems from two different perspectives (organizational and technical risks) by applying vulnerabilities assessment and penetration testing, which is finally organized into a risk assessment plan. Furthermore, a risk mitigation plan is developed in order to eliminate these identified risks. During the case study, ISO/IEC 27001:2005 ISMS have been developed in order to eliminate the risks that face the HU information systems. The ISMS provides the required policies and controls in order to minimize the identified risks and minimize the likelihood of new vulnerabilities emersion. The provided ISMS should facilitate examining and enhancing the information security experience of HU-ICET.

ISO/IEC 27001:2005 ISMS is among the most strict information security standards that guarantee an ultimate secure environment for technology based organization. The ISMS takes care of almost every single side affecting the organization's security experience by applying the needed tools and procedures to insure confidentiality, integrity, and the availability of the information system. During the development of the ISMS, an information security policy must be development to standardize the procedures developed by ICET; this includes identifying the personnel's responsibilities from an information security perspective. Regular updates of the information security policy are applied and reviewed until every single transaction inside ICET is controlled by these policies. In this paper, we have introduced an information security policy, the ICET. Procedures should also be developed to insure a standardized communication mechanism inside ICET for different operations. ISMS also goes beyond the vulnerability assessment and penetration testing by applying a risk management [1] methodology, which is a continuing process of identifying the vulnerabilities mapped to their risk profile and of proposing a mitigation process.

Section 2 of this paper includes a brief background material on topics concerning vulnerability assessment, penetration testing, and ISMS. It starts with a brief overview of the vulnerability assessment and penetration testing and its importance for information systems; moreover, it addresses one of the methodologies used in penetration testing, which is the backtrack methodology. In addition, ISMS is discussed in details and reflected on ISO27001 ISMS, showing the importance of this standard as a complete solution for information security against the rapidly growing number of security breaches.

In Section 4, we introduce the steps of implementing ISO27001 ISMS; it starts with identifying the scope of implementation. After that, it addresses the proposed information security policy which is designed to meet the requirements of ICET. The policy contains controls that have two different perspectives: technical and organizational. An example of the technical perspective is the password policy which addresses the confidentiality techniques to be used, such as using SSL/TLS and the minimum number of char's to be used and their space (e.g. char's lower and upper as well as numbers). The physical security policy also identifies the technical control for protecting the assets from a physical perspective (e.g., logging control, door/looks). An example of the organizational policies is the strategy and planning policy which identifies the need for security administrator/officer position in the ICET. Access control policy addresses the appropriate personnel privileges. The risk management methodology is addressed, after which the risk assessment and risk mitigation plans are presented.

Section 5 will conclude the paper, showing that the final results of the paper proved to be better than the ones expected a year ago when the study was first launched. Moreover, it will present our future plans concerning this research.

The main contributions of this paper are the following:

- To enrich knowledge in the fields of Information Security (IS), Information Security Management Systems (ISMS), and Penetration Testing.
- To evaluate the information security level at The Hashemite Kingdom of Jordan Universities generally and the HU specifically by applying a case study on the HU, one of the leading university in Jordan.
- To define and prioritize the HU information assets affecting its business continuity.

- To define and prioritize vulnerabilities affecting the information assets of ICET at technical and organizational levels.
- To implement ISO/IEC 27001:2005 ISMS for the scope of ICET, including development of an information security policy in addition to risk assessment and risk mitigation plans to provide the solutions needed to eliminate the existing vulnerabilities.

2. Background

2.1. Vulnerability

Vulnerability is a weakness point of an asset or group of assets that can be exploited by one or more threats [2], and results can potentially compromise the confidentiality, integrity and/or the availability of services. Attacks are the processes of exploiting an existing vulnerability. Attacks are divided into two sub-categories based on their effect on the security requirements, namely, active, and passive attacks. They are called active when the attacks affect the services by compromising the integrity or availability, and passive when they affect the information confidentiality only. The attack itself is a threat for the information system, and every threat has a specific risk based on the vulnerabilities. Figure 1 illustrates the relationship between vulnerabilities, threats, and risk [3].

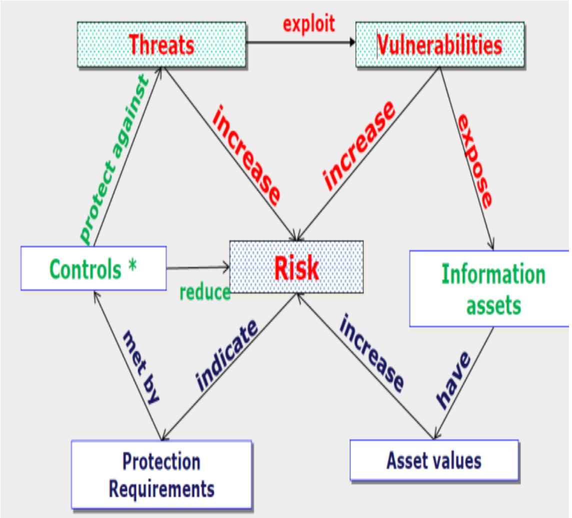


Figure 1. Relation between threat, vulnerabilities, and risk

Based on ISO27005:2008, vulnerabilities are classified according to the asset class they are related to. The following chart in Figure 2 illustrates this classification [2]:

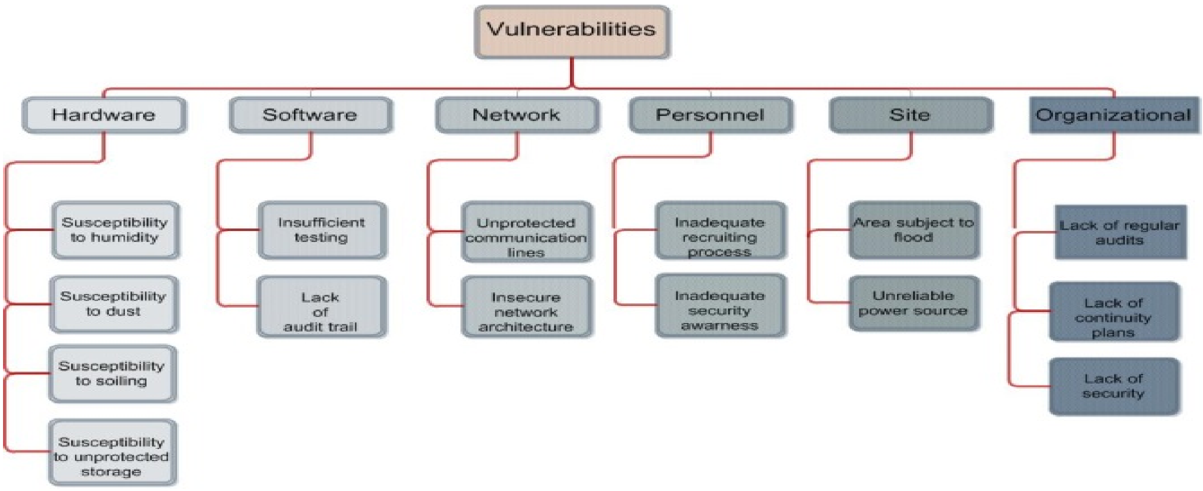


Figure 2. Vulnerabilities classification according to the relating asset class

According to the chart above, hardware components are affected by humidity, dust, and soiling, where the unprotected storage is another vulnerability that must be also taken into consideration. Hardware vulnerabilities are relatively easier to detect, but the damage can be huge and irreversible. We can control hardware security by hardware sighting and monitoring, with respect to equipment security. On the other hand, software is easier to exploit by attackers due to insufficient testing and lack of an audit trail. It is possible to handle these vulnerabilities by doing internal/external a vulnerability test where we can summarize a list of recommended fixes, or build a software trail from the beginning to keep track of the qualities of software, or audit the current software.

The most commonly exploited vulnerabilities by attackers are network vulnerabilities. Because all internal and external communications of any company are based on a network, unprotected communication lines and insures network architecture is serious risks. To reduce this vulnerability, it is important to build the network infrastructure securely and use suitable cabling methods in an appropriate way from the beginning. Using a firewall is a good idea, even though it has its own problems.

Personnel risks are more difficult to manage because they are abstract. The key risk indicators refer to the poorly recruited candidates, and the current employees who are not aware of the security process. In response to personnel vulnerability, audit employees access the IT systems, set access privileges for everyone, train employees to increase security awareness, including ethics and the use of policies, and separate employees duties by setting standards and guidelines for the system's development staff.

Unexpected external threats, such as flood and unreliable power source, are vulnerabilities depending on the site; a company should realize the occurrence of a risk, put the necessary disaster planning steps, and use generators and power back-ups to present the data lost during power outage [4,5].

The lack of monitoring and auditing policies and procedures causes organizational vulnerabilities. To reduce them, the organization should build preventive IT controls. Tests to confirm and validate the correctness of data, auditing, and monitoring must be done.

2.2. Vulnerability Assessment and Penetration Testing

Under the enormous number of attacks that infect many organizations and companies caused by the existence of the information system vulnerabilities, Vulnerability Assessment and Penetration Testing came as tools to identify and quantify the system weakness points in order to improve the security controls and services that protect the information assets. They also give a better understanding about the weaknesses in the existing information system.

Vulnerability assessment is the evaluation of the information technology infrastructure of the organization; it tends to identify the weakness of these infrastructure components and how to control in order to protect from threats and attacks. Vulnerability assessment is an important activity to understand most of the various vulnerabilities in a system that might compromise its critical information assets. Penetration Testing is the process of exploiting the discovered weakness points by a malicious user. The tester needs to gather information, enumerate the vulnerabilities, and finally exploit the given vulnerabilities and gain access to the system [4].

There have been various methodologies introduced to address security assessment needs. The BackTrack testing methodology is one of the methodologies proposed for these purposes. BackTrack is a Linux-based platform aimed for the purpose of penetration testing and security auditing with advanced tools to identify, detect, and exploit any vulnerabilities uncovered in the target network environment. It is very commonly used for this purpose where studies show that as the end of July 19, 2010, BackTrack 4 has been downloaded by more than 1.5 million users. [6] This platform provides users with large collection of security related tools ranging from port scanners to password crackers, applying appropriate testing methodology with defined business objectives and a scheduled test plan will result in robust penetration testing of your network. BackTrack is the official operating system that is used in this study, in addition to windows OS. BackTrack testing methodology which is shown in Figure 3 is implemented in this study.

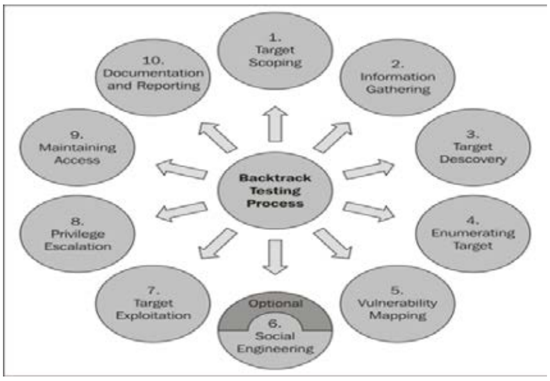


Figure 3. BackTrack testing methodology

1. Target scoping:

To make a successful penetration testing, we must take into consideration the technology under assessment and its basic functionality. An auditor must understand the given scope for the target network environment before starting the security assessment; this step will take him one step closer to the purpose.

2. Information gathering:

It is also called reconnaissance phase. During this phase, we should gain information using a number of publicly available resources; the more information we gather, the more chances for the success of penetration testing we gain. This information can be gathered using various methods.

3. Target discovery:

This phase deals with identifying the target status, operating system, and its network architecture. This process provides a full image of the technologies interconnected. By using tools available in Backtrack, it is possible to determine the live network hosts, and identify the operating systems running on these machines.

4. Enumerating target:

This phase is for finding the open ports on the target systems. Scanning may help in determining the port visibility with a number of port scanning techniques such as full open, half-open, and stealth; it sometimes works even if the host is behind a firewall or an Intrusion Detection System (IDS). These ports can be enumerated for the running services.

5. Vulnerability mapping:

This phase tends to identify the vulnerabilities based on the valuable information that has been gathered about the target network. This process can be done through using a number of automated network vulnerability assessment and Backtrack tools.

6. Social engineering:

When there is no other way available for an auditor to enter the target, the art of deception takes place. A successful penetration may require watching the human psychology before applying the suitable deception technique against the target.

7. Target exploitation:

After examining the revealed vulnerabilities, now it is possible to penetrate the target system. This phase may require modification on the existing exploit; backtrack tools are provided to accomplish this process.

8. Privilege escalation:

Once the target is acquired, the penetration is successfully done. Now we can escalate access privileges using any local exploit that matches the system environment; once they are executed, super-user access or system-level access privileges are attained. After this phase, it is possible to launch other attacks against the local network systems.

9. Maintaining access:

Sometimes maintaining access to the system without applying any noisy behavior is required for a specific period of time. Such activity can be used demonstrating illegal access to the system without applying the penetration testing process again, which saves time, cost, and resources being used. Using some secret tunneling methods, that make use of protocol or end-to-end connection strategy leads to establishing a backdoor access and maintains the auditor's presence in the target system as long as required.

10. Documentation and reporting:

Presenting Documentation and reports about the vulnerabilities found and exploited is the ethical and the final step in the penetration testing methodology. These documents are very important because the concerned technical team will check the method of penetration and will try to close any security loopholes that may exist.

2.3. Information Security Management System (ISMS)

Information Security Management System (ISMS) is a management plan which specifies the requirements for the implementation of security controls customized to the needs of organizations. The ISMS is designed to protect the information assets from any security breaches.

ISO27k is a series of international standards for Information security management. This standard covers all types of organizations (e.g., commercial enterprises, government agencies and non-profit organizations) and all sizes from micro-businesses to huge multinationals.

ISO/IEC 27001:2005 standard is a process of applying security management controls on organizations to obtain security services in order to minimize assets' risks and ensure business continuity. The main security services that present the C-I-A triad taken into consideration are [7]:

A. Information Confidentiality.
B. Information Integrity.
C. Services Availability.

This international standard adopts a model called Plan-Do-Check-Act (PDCA) model, which is applied to structure all ISMS processes. Figure 4 illustrates the PDCA model.

Figure 4. Plan Do-Check-Act model

1. Plan: Is the process of establishing the ISMS by applying the policies and objectives of the ISMS as well as developing the procedures concerning managing the risks.
2. Do: Is the process of implementing and operating the ISMS which was planned in the previous step.
3. Check: Is the process of monitoring and reviewing the ISMS by measuring the performance against the applied controls including policies, and, finally, exporting the results to management review.
4. Act: Based on management reviews, in the previous step, improvements of the applied ISMS is taking place.

Security experts say and statistics confirm that:

- Information technology security administrators should expect to devote approximately one-third of their time addressing technical aspects. The remaining two-thirds should be spent developing policies and procedures, performing security reviews and analyzing risk, addressing contingency planning and promoting security awareness;
- security depends on people more than on technology;
- employees are a far greater threat to information security than outsiders;
- Security is like a chain. It is as strong as its weakest link;
- the degree of security depends on three factors: the risk you are willing to take, the functionality of the system and the costs you are prepared to pay;
- Security is not a status or a snapshot, but a running process.

These facts inevitably lead to the conclusion that security administration is a management issue, and not a purely technical issue [8,9].

We will be discussing the details of implementation steps in Section 3.

3. Proposed ISO27001 Based ISMS for HU ICET

3.1. Proposed Scheme

An introduction about ISMS is discussed in Section 2, which has the background material. In this section, we will be addressing the ISMS management framework in addition to the implementation steps of ISO/IEC 27001:2005. ISMS management framework describes the systematic and structural approach of managing information security at ICET. It defines the key elements of information security management and also the ways it is implemented and maintained. Figure 5 illustrates the implementation steps needed for the ISO27k. This will be discussed in details in the next subsections.

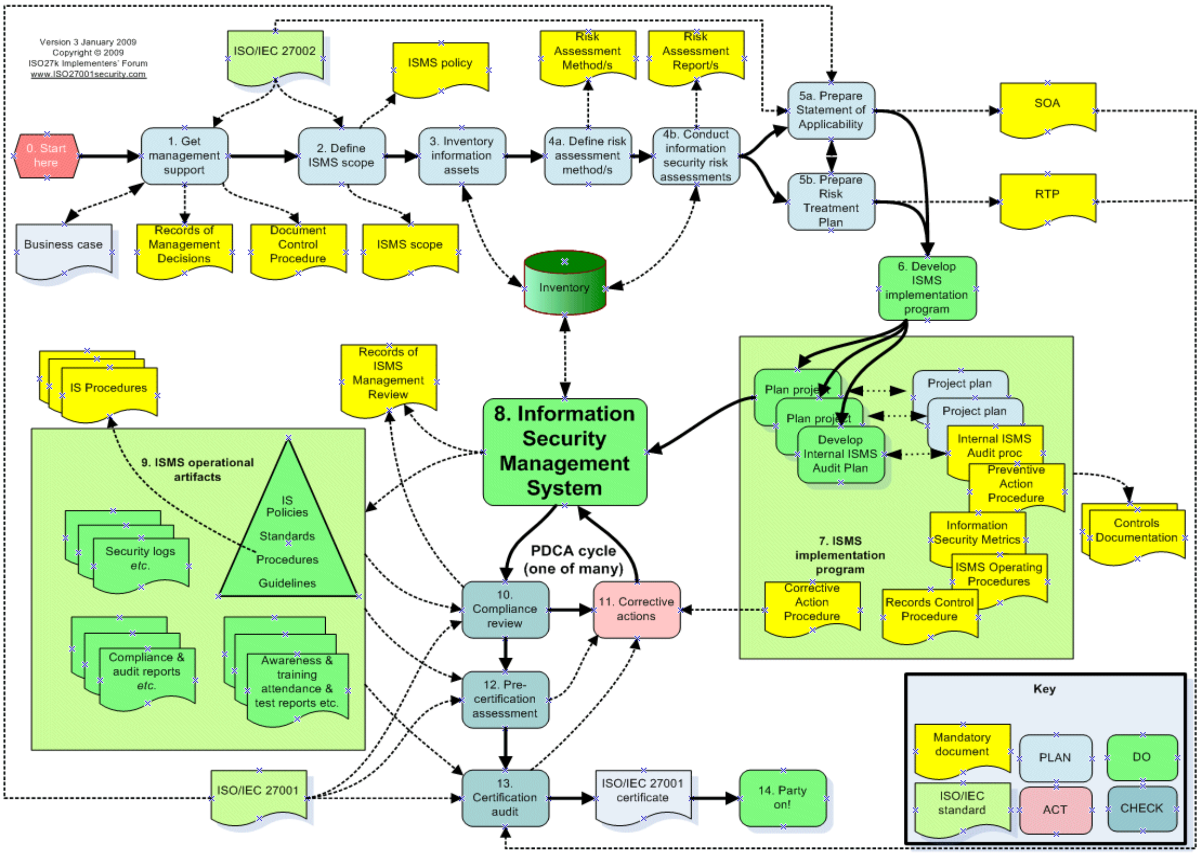


Figure 5. ISO27K implementation steps

In this paper, our work starts with step (0) of Figure 5, and ends with step (6) including the Statement of Applicability (SOA) and the Risk Treatment Plan (RTP). By finishing the previously mentioned steps, we will finish all the required planning requirements for the ISO2k standard. Planning is the process of establishing the ISMS by applying the policies and objectives of the ISMS as well as the developing of the procedures concerning managing the risks, in addition to finishing most of the required documented works which are the policies, scope, risk assessment methods, risk assessment plan, risk mitigation plan, and statement of applicability (SoA).

By this the ICET will be ready to start the DO (the green color in Figure 5) step which is the process of implementing and operating the ISMS, which was planned in the previous step.

After that, there will be some CHECKING (the dark blue color in Figure 5) which is the process of monitoring and reviewing the ISMS by measuring the performance against the applied controls including policies and finally exporting the results to management review. Checking steps are steps 10, 12, and 13 from Figure 5. The certificate audit (step 13) is done by a certified iso27001 lead auditor which will result in some **ACT** steps according to the management reviews and auditor recommendations. Based on the auditor report, the ICET will or will not receive the iso27001 certificate being the second organization in Jordan to get the iso27001. It is to be noted that the first organization who got the certificate was ZAIN Telecommunication Company [10]. The final implementation step (number 14), which is a DO step, implies that a party should take place after all the hard work established by ICET until the accreditation.

We defined the scope of our study to be the Hashemite University ICET Computer Center. The main problem we faced was in step (3) where we adopt a black-box methodology, which means that we should treat the ICET as a black box. We made our own assets inventory by identifying the most important assets in the center.

3.1.1. Establish the ISMS for ICET

A. Define the scope of the ISMS.
B. Define an ISMS policy.
C. Define a systematic approach to risk assessment.
D. Identify the risks.
E. Assess the risks.
F. Identify and evaluate options for the Mitigation of risks.
G. Select control objectives and controls for the Mitigation of risks.
H. Prepare a Statement of Applicability (SoA).
I. Obtain management approval of the proposed residual risks and authorization to implement and operate the ISMS.

- *Documentation Requirements*

ISMS Documentation shall contain:

A. Documented ISMS Policies.
B. Documented ISMS Procedures.

C. Documents needed by the organization to ensure planning, operation and control of the ISMS processes.
D. ISMS records depicting the proof of implementation and improvement.

- *ISMS Scope*

Information assets of Hashemite University ICET Center for which the computer center has the assigned authority of or responsibility for administrating and managing information assets.

- *Information Security Policy*

Information security management in ICET center should be taking the issue of security management very seriously. These information security policies are applied to all the employees.

- *Risk Assessment*

Risk assessment is a very important topic in our project.

- *Risk Mitigation*

A Risk Treatment Plan (RTP) which is a coordination document defining the actions to reduce unacceptable risks and to implement the required controls to protect information assets. For each identified risk, the Risk **Treatment Plan shows:**

A. The method selected for treating the risk.
B. What controls are in place.
C. What additional controls are proposed.
D. The time frame over which the proposed controls are to be implemented.

- *Controls to be applied*

The risk management process will have identified critical areas of risk, as well as areas of lesser risk. Some controls are not applicable to every environment and may be used selectively according to local circumstances. The needed ISO 27001 applicable controls should be decided.

- *Statement of Applicability*

The Statement of Applicability (referred to as SoA) is a document that describes which of the 133 controls of ISO 27001 are applicable to Hashemite University Computer Center. Figure 6 illustrates the security process of the establishment.

3.1.2. Risk Management Methodology

Risk management will be presented and designed to mitigate the Hashemite University network. By applying this step, the ICET will be able to operate, monitor, maintain and improve its Information Security Management System according to the requirements of ISO/IEC27001:2005. Table 1 shows the information security risk management activities according the four phases of the ISMS. process [1]:

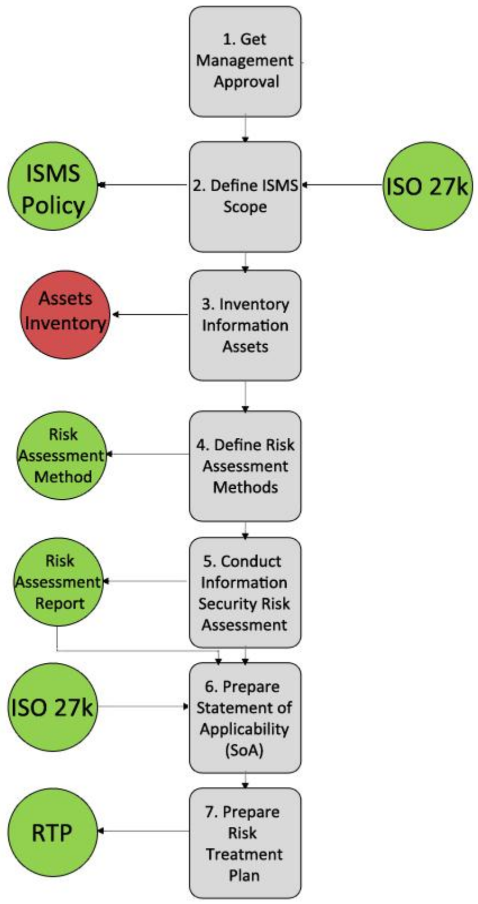


Figure 6. Security process

Table 1. Alignment of ISMS and information security risk management process

ISMS Process	Information Security Risk Management Process
Plan	Establishing the context Risk assessment Developing risk treatment plan Risk acceptance
Do	Implementation of risk treatment plan
Check	Continual monitoring and reviewing of risks
Act	Maintain and improve the Information Security Risk Management Process

The Hashemite University, as any other organization, faces a struggle in keeping its network secure from inside and outside influences (threats), and in order to keep the business continuity, we need to draw a plan that defines these threats and their impact on the organization and propose a method of how to mitigate them before they pose a great risk on the institution. Plus to continue monitoring the risk management plan on the organization. The ISO 31000 standard is designed to and intended for implanting risk management codified by the Standardization; the purpose of these standards is to set some boundaries and guidelines regarding the risk assessment and management. Figure 7 illustrates the risk management process. Beneath it, we explain each step and show how we implemented it on the ICET.

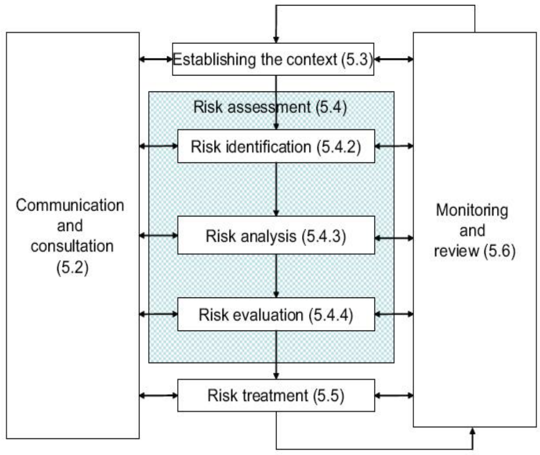


Figure 7. ISO 31000 risk management process

Risk management process consists of many stages according to the ISO 31000:

- *Communication and consultation*

All the risk information obtained from the risk management must be exchanged or shared between the decision-maker and the stakeholders based on an agreement. The communication is needed with the stakeholders in order to document their perception of the risks and their classifications of the assets values. In order to satisfy this procedure, we have distributed a survey to the employees of the computer center, asking questions regarding some ISMS policies. We did our best to keep the survey short and ask very obvious and short questions. Table 2 shows the result of these surveys:

Table 2. Survey results

The Assets		Assets value				
Site	OS	Very high	high	moderate	Low	Very low
Oracle application server	Sun Solaris 10	X				
Mail server "mail.hu"	Microsoft Windows Server 2003 SP2	X				
labsrv.labs.hu 10.238.0.18	Microsoft Windows Server 2003 SP2		X	X		
Hu-database-115	Sun Solaris 10	X				
Hu.edu.jo (87.236.232.218) 87.236.232.216	Sun open Solaris 2008.11	X				
Hu.edu.jo (87.236.232.220) 87.236.232.216	Microsoft Windows	X				
Hu.edu.jo (87.236.232.223) 87.236.232.216	Cisco 870 router or 2960 switch (IOS 12.2 -12.4)		X			
WEBREG 10.238.0.45	Server 2008 Enterprise Edition SP2		X			
EZPROXY 87.236.232.210 -87.236.232.15	Microsoft Windows Server 2003 SP2		X	X		
Juniper 87.236.232.194	NetScreen Screen OS	X				
Web portal	Microsoft Windows		X			
Juniper 87.236.232.195	Juniper Networks SSG 20 firewall	X				

The results of this survey helped us in preparing the risk treatment plan; we used the results to help us in the risk prioritization. Table 3 is about checking the applicability of ISMS policies on the organization:

Table 3: Statement of applicability

Question	Yes/No	ISO27001 Control
Is there a document describing the security policy related to information systems and in particular the organization, management and piloting of security (roles and responsibilities) as well as the fundamental principles underlying information security management?	NO	5.1.1
Is there a procedure for regularly updating organizational documents related to information systems security in line with changing organization structures?	NO	6.1.8
Are information systems covered by an insurance policy which accounts for material damage (fire damage, miscellaneous risks and accidents, damage to machines, all computing risks, "all risks except", named risks etc.)?	NO	
Are the information systems covered by an insurance policy which covers non material damage (malevolence, non authorized usage, and accidental loss of data or programs, denial of service)?		
Is the site completely enclosed by a perimeter fence which is difficult to cross or to scale? For a building on the public highway to be considered secure, all windows on the ground floor must be locked shut and all access points must have been taken into consideration (garages or underground car parks, roof etc.)	YES	9.1.1
Are the automatic access control systems under 24 hr surveillance enabling the detection of a failure, a system deactivation or the usage of emergency exits in real time?	YES	9.1.1
Is there an operational intrusion detection system to the site, linked to a 24 hr monitoring center?	YES	9.1.1
Has a thorough and systematic analysis of all the conceivable environmental risks for the site been conducted? Potential risks are : Avalanche, hurricane, storm, flooding, forest fire, land slide, earthquake, Volcano, broken dam or dike, torrential flood, falling rocks, collapse, gullies, drought	NO	9.1.4
Has a thorough and systematic analysis of all the conceivable industrial risks for the site been conducted? Potential risks are: high risk site nearby (Seveso like), dangerous internal installations, gas station, transport of dangerous materials...	NO	9.1.4
Is there a complementary video surveillance system, complete and coherent, for protected office areas, able to detect movement and abnormal behavior?	NO	
Is there a general control of movement of visitors and occasional service providers (time stamping at arrival and departure, signature of the person visited, etc.)?	NO	9.1.2
Are visitors and occasional service providers recorded in such a way as to enable a subsequent verification of the reason of their visit and has a procedure been put in place which enables the detection of dishonesty or abuse?	NO	
Is there an air conditioning system which regulates air quality (temperature, pressure, water content, dust) corresponding to the specifications of builders of installed equipment?	YES	9.2.2
Has there been a systematic and exhaustive analysis of all the possible points at which water might enter? For example: position of locations relative to natural overflows in the case of flood or violent storms, flooding from floors above, rupture of hidden or exposed pipes, usage of fire extinguisher systems, overflow of water evacuation conduits, untimely start of humidifier systems etc.	NO	9.1.4
Is there an automatic fire detection system for sensitive locations (raised floors and false ceilings if they exist)?	YES	9.1.4
Is there a possibility to declare sites or remote access points as sensitive and, as such, requiring an authentication of the entity accessed?	YES	
Is there a mechanism of authentication of the entity called before access to sensitive sites from the internal network?	YES	
Is access to the various parts of the information system (applications, data bases, systems, equipments, etc) defined in terms of job profiles which regroup roles or functions within the organization (profiles define access rights which are available to holders of the profile)? Note: in certain circumstances the notion of "profile" may be replaced by the notion of "group".	YES	11.2.2
Is there a regular audit at least once a year of all rights attributed to each profile and the profile management procedures?	YES	11.2.4
Are the archive storage locations under permanent video surveillance?	NO	
Does the procedure and mechanisms of storage, distribution and exchange of keys and more generally the management of the keys offer solid guarantees which merit confidence and are they approved by the Information Security Officer?	YES	12.3.2
When changes are made to the operating systems, is there a review and test of their impact on the applications?	YES	12.5.2
Are all change requests for an application subject to a formal review procedure (requestor, rationale, decision process)?	YES	12.5.1
Are the decisions to change or update users' software versions subject to a control procedure (registration, planning, formal approval, communication to all concerned individuals, etc.)?	YES	10.1.2; 10.3.1
Does the Hashemite University have a formalized risk-analysis process that includes the identification and prioritization of risks and the development of an action plan?	NO	
Does the Hashemite University have an advisory group that cuts across different departments to facilitate the risk management process?	NO	

The answers to this survey help in building the risk mitigation plan as well as defining the risks posed to the organization, though some answers were misleading. However, we used the answers in the risk treatment plan.

- *Establishing the context*

Defining the scope of our work is performed by discovering all the assets using many vulnerabilities scanners such as Nexpose, Metasploit Pro, Web-securify [11].

- *Risk assessment*

This is the step where we identify the information assets that are of value to the Hashemite University ICET Center, the threats and the vulnerabilities of information assets, the existing controls present to counter the identified threat and assess the probability and the impact of the threats on the Hashemite University Computer Center. Then risks are determined and prioritized. Finally, the control effectiveness of the implemented controls are measured. Figure 8 illustrates the stages of risk assessment:

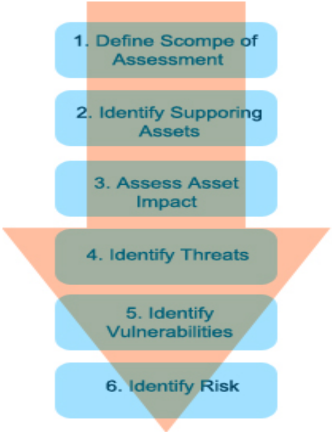


Figure 8. ISO 31000 Risk Management Process

- *Risk Identification*

Defining the scope of risk assessment includes the services provided by the assets listed in the Information Asset Inventory based on their importance to Hashemite University ICET Center, then we can specify the application of controls as required by ISO/IEC 27001:2005 and ICET Center Standards (if available). In this step we identify and list all the supporting assets that compliment and support supplying the information technology services provided. As in the information asset inventory, each identified supporting assets shall be mapped to relevant service offering covered under the scope of Risk Assessment, which is describes previously in Figures 5 and 6.

- *Risk Analysis*

After running vulnerability scan on the assets, and after defining the real vulnerabilities on each asset, the rule of risk analysis pups up. Risk analysis is the process to decide the nature of risk and to determine the level of the risk; it provides the basis for risk evaluation and decisions about risk treatment. Risk analysis includes risk estimation; when estimating the level of the risk two factors should be taken into consideration:

a) The impact of the vulnerability:

The impact rating of each identified supporting asset shall be high, medium or low, taking into consideration the availability importance of services. The severity of each vulnerability is usually defined by global organizations such as CVE (common vulnerabilities and exposures), and CERT which is the United States computer emergency team [12].

b) The likelihood:

Likelihood is defined as the chance of something happening. In this context, it refers to the chance of occurrence of a specific threat based on the vulnerability, it can be determined objectively or subjectively, qualitatively or quantitatively. The ratings are identified as high, medium or low. In the calculation of risk assessment, the term “Probability” is the equivalent of the likelihood [13].

The following will provide the factors to be considered during the rating of an identified vulnerability:

High	In order to exploit the vulnerability, it would require minimal resources and have maximum probable opportunities.
Medium	In order to exploit the vulnerability, it would require minimal resources but have little opportunity or low probabilities. Or, to exploit the vulnerability, it would require a high degree of resources and have maximum probable opportunities.
Low	In order to exploit the vulnerability, it would require a high degree of resources and have minimal opportunity.

Risk is the outcome of an incident, when a threat successfully exploits the weakness present in an asset. Risk will have a negative impact on an entity or organization. Risk can be measured as the product of an asset impact and a probability that a weakness in an asset will successfully be exploited by a threat action. Risk Assessment Methodology:

- *Risk evaluation*

The purpose of this step is to assist in making decisions and, especially, in risk treatment and the priority for the treatment implementation based on the outcomes of risk analysis. The risk evaluation can lead to a decision not to treat the risk (risk acceptance). Figure 9 illustrates the risk determining matrix. Based on the determined risk, the risk should be rated from 1 to 6 as illustrated in Table 4. Risk rating helps in the prioritization of risk treatment which will be discussed in the next step, i.e., risk treatment.

Probability \ Impact	High	Moderate	Low
High	H/H	H/M	H/L
Medium	M/H	M/M	M/L
Low	L/H	L/M	L/L

Figure 9: Risk Determining Matrix

- *Risk treatment*

This is the second phase of risk management and it is the process of applying adequate protection, based on a management decision to reduce, avoid, transfer and accept risk. An overall planning for the treatment of identified risks should be formulated based on the risk assessment report. All risks identified during risk assessment may not have the same level of impact on Hashemite ICET Center information assets and all recommended controls may not necessarily mitigate the identified risk in a cost effective manner. Risk treatment involves suggesting options for modifying risks, and implementing those options plus prioritizing risk treatment and offering risk mitigation techniques as well as defining the risk treatment option. Detailed planning and management approval sorting shall be done before treating the identified risks. A risk treatment plan is shown in Figure 10. For all the assets investigated, we offered the risk treatment option and added the required controls plus the ISO 27001 compliance for each vulnerability.

After analyzing all these risks and threats (Figure 10), we found out that most of the solutions to these vulnerabilities were:

1. Turning off some services or capabilities related to the vulnerability.
2. Adding access controls using firewalls or network borders.
3. Increasing monitoring to detect or prevent attacks (monitor the intrusion, prevention system) for 24 hours a day.
4. Raising the employees awareness about the vulnerability, giving them courses regarding these matters.
5. Testing and evaluating the patches, before installing, to ensure that they are effective and will not be any side effects.

3.2. Information Security Policies

3.2.1. Planning Policy

The objective of planning is to implement information security, and establish information security plans for the systems.

- *Information Security Planning Policy*

a) Information Security Officer must be established and filled by ICET that will be responsible for the leading and management of the ICET information security program.
b) The scope of each service must be defined in terms of its supporting assets, assets owners, and its technologies.
c) A risk profile must be created for each included service which should include identification of risks to the assets. Identification of risks must include threats to assets, vulnerabilities that may be exploited by the threats, and the possible impact that loss of CIA (confidentiality, Integrity, and Availability) on the assets.

3.2.2. Requirement Policy

The objective of policies and standards is to define the requirements and responsibilities that the users/employees must follow.

- *Information Security Policy*

An information security policy document must be established to manage the information security experience for the ICET. This document must set all applicable policies, security responsibilities and supporting information security procedures for the ICET. It must be reviewed and updated as necessary.

- *Statement Policy*

a) Security policy should have a clear statement which should include the vision measures for the ICET that should be protected.
b) Confidentiality, integrity, and availability of information should be met. Business continuity plan should be produced maintained and tested.
c) Defining the acceptable risk ranges, otherwise it will be considered for risk treatment.

3.2.3. Risk Management Policy

The objective of risk management is to manage threats and vulnerabilities facing ICET assets.

- *Risk Assessment Policy*

a) A risk assessment must be executed on all services at least once every three years or whenever major changes to the services occur.
b) Ongoing monitoring as well as mitigation of risks against different risks must be conducted.

*3.2.4. **Awareness** Policy*

The objective of awareness and training is to provide a formal technique for educating the employees of the ICET regarding their responsibilities with respect to information security.

a) The security officer must lead ICET wide security awareness campaign that delivers targeted information security awareness to all services users.
b) All employees of the ICET must receive appropriate training which must cover security requirements and legal responsibilities, as well as instruction in the correct use of information processing (e.g. logging to server remotely) before access to information or service is granted.

OS	Supporting host asset	Risk vulnerability	Severity	Risk treatment option	Mitigation/acceptance	ISO 27001 Compliance
Microsoft Windows Server 2008 Enterprise Edition SP2	10.238.0.45/WEBREG	MS12-020: Vulnerabilities in Remote Desktop Could Allow Remote Code Execution (2671387) (windows-hotfix-ms12-020)	High	Risk modification	Download and install Microsoft patch windows6.0-kb2621440-x64.cab (632043 bytes)	10.4.1,12.2.2
		SMB signing disabled (cifs-smb-signing-disabled).	Medium	Risk modification	Configure the system to enable or require SMB signing as appropriate. Note: ensure that SMB signing configuration is done for incoming connections (Server).	
		SMB signing not required (cifs-smb-signing-not-required)	Medium	Risk modification	Configure the system to enable or require SMB signing as appropriate. The method for doing this is system specific ,Note: ensure that SMB signing configuration is done for incoming connections (Server).	
		Database Open Access (database-open-access)	Medium	Risk modification	Configure the database server to only allow access to trusted systems	11.6.1/11.6.2
		ICMP timestamp response (generic-icmp-timestamp)	Low	Accepted	disable the service	11.4.1
		TCP timestamp response (generic-tcp-timestamp)	Low	Risk modification	Disable TCP timestamp responses on Windows Set the Tcp1323Opts value in the following key to 1: HKEY_LOCAL_MACHINE\System\CurrentControlSet\Services\Tcpip\Parameters	11.4.1
	10.238.16.4/DNS	DNS server allows cache snooping (dns-allows-cache-snooping)	Medium	Risk modification	Restrict the processing of DNS queries to only systems that should be allowed to use this nameserve	10.6.1,
		Nameserver Processes Recursive Queries (dns-processes-recursive-queries)	Medium	Risk modification	Restrict the processing of recursive queries to only systems that should be allowed to use this nameserver.	11.6.2
		LDAP Anonymous Directory Access Permitted (ldap-anonymous-directory-access)	Medium	Risk modification	Disable anonymous access from the "Anonymous" tab of the LDAP protocol configuration in the Exchange Administrator.	11.4.4 ,11.4.6
		LDAP Anonymous Directory Access Permitted (ldap-anonymous-directory-access)	Medium	Risk modification	Disable anonymous access from the "Anonymous" tab of the LDAP protocol configuration in the Exchange Administrator.	11.4.4 ,11.4.6
		ICMP netmask response (generic-icmp-netmask)	Low	Risk modification	Disable ICMP timestamp responses on Windows Vista/2008 ICMP timestamp responses can be disabled via the netsh command line utility. Go to the Windows Control Panel.	11.4.1

Figure 10. Risk treatment plan

3.2.5. Performance Management Policy

The objective of performance management is to provide metrics to measure progress of the information security program.

a) ICET shall develop measurement procedures to measure the performance of the implemented information security management system, in-line with ISO27001:2005 standard.
b) The Security Officer shall monitor the effectiveness and efficiency of controls in-line with standard requirements.

3.2.6. Assets Management Policy

The objective of asset management is to maintain appropriate protection of assets by assigning assets owner(s) and the acceptable use of assets.

- *Inventory of Assets Policy*

a) An inventory of the important assets associated with each service must be produced. Each asset must be clearly identified along with its ownership.
b) Movement of physical IT assets shall be done only after approval from the IT manager; any changes in location of physical assets such as servers shall be updated in the asset inventory.
c) Software license inventory shall be maintained and updated on purchase of new license or on removal.
d) The loss, theft of assets shall be reported immediately to the IT manger/ Security officer.

- *Ownership Polic*

a) Each information asset shall have an owner who will be responsible for the assets that they own.
b) Asset owners will be responsible for ensuring that they have the correct skills and tools for protecting their assets to meet the security policies requirements.

- *Classification policy*

a) Information shall be classified considering the impact of loss of confidentiality, integrity, and availability.
b) Information assets available at the ICET shall be classified as Confidential, Internal and Public:
- Confidential: Information that is extremely sensitive and is intended for use only by named individuals within ICET.
- Internal – For Official Use Only: Non-sensitive information intended for distribution within ICET Only.
- Public: Non-sensitive pieces of information that are meant for release to general public

3.2.7. Physical Security Policy

The objective of physical security is to provide standards for the protection of personnel, hardware, software, and data from physical circumstances that could cause serious losses or damage to the ICET. This includes protection from fire, and natural disasters.

- *Physical Security Policy*

a) The security perimeter must be clearly documented.
b) The perimeter of the ICET building must be physically protected, i.e., there must be no gaps in the perimeter or areas where a break-in could easily occur. External walls of the site must be of solid construction and all external doors must be suitably protected against unauthorized access by appropriate control mechanisms (e.g. alarms).
c) Controlling physical access to the ICET building must be in place; access to ICET building is restricted to authorized personnel only.
d) Secured areas must be clarified and must be protected by appropriate entry controls to ensure that only authorized personnel are allowed access.
e) Doors and windows must be locked when unattended, and external protection must be considered for windows particularly those at ground level.
f) Visitor log book shall be used to record all visitors entering and leaving a secure area such as the server's room. Visitors should register details, such as name, date, entrance-time, and exit-time.

- *Supporting Utilities and Equipment's Policy*

a) Equipment shall be protected from power failure.
b) All supporting utilities such as electricity, air conditioning must be adequate for the systems they are supporting.
c) All servers and network equipment's hosted in the data center shall be provided with uninterruptible power supply system (UPS) to facilitate orderly shutdown of the information system in the event of a primary power failure.
d) The UPS should ideally protect all the ICET information processing assets, within the data center.
e) The air conditioners shall be checked for effective functioning regularly.
f) The air conditioning system should be effective and the temperature in the data center should be monitored. The server room should have temperature monitoring devices and it should be ensured that the temperature should always be maintained in appropriate levels.
g) Air conditioning should be provided on a 24-hour basis.
h) It must be ensured that the UPS is not switched off and that the power cord is properly secured to the equipment. Checking the functionality of batteries is necessary as well.
i) It must be ensured that no unauthorized person tamper or change the switch settings on the UPS.

- *Cabling Security Policy*

a) Power and cabling into data centers will be underground or will provide the required protection from any interference or damage.
b) Cabling maps should be made available and updated regularly.
c) All cables should be labeled and tagged.

3.2.8. Operation Management Policy

The objective of operation management is to introduce procedures to manage the information processing and administer their management.

- *Operating Procedures Policy*

The ICET center must provide the operators with documents showing the tasks and responsibilities of employees involved in information systems operations.

- *Capacity Management Policy*

a) Capacity of all servers must be monitored regularly and reported to the security officer.
b) Hardware capacity monitoring must include:
- Disk Space Capacity.
- Processors Utilization.
- Main Memory.
- Network Interfaces Utilization.

- *System Acceptance Policy*

a) Acceptance criteria for a new information system, upgrades and new versions should be established after suitable tests of the system before acceptance, some controls that should be considered during acceptance testing includes:
- Security controls in place.
- Performance and system capacity requirements are defined.
- Error recovery, restart plans are established.
- Training for the users in the operation or use of the new system.

b) All in-house developed system shall have appropriate documentation and functional requirements, technical specification, testing acceptance, and user's manuals prior deploying the new system.
c) Risk evaluation related to the introduction of new information systems, upgrades must be established before acceptance, and risk mitigation of risks shall be initiated, before acceptance.

- *Backup Policy*

a) Valuable, critical information must be backed up periodically.
b) b) Daily backup must be applied for all very sensitive information.
c) ICET management must define which information and system are to be backed up, the frequency of backup, and methods.
d) Disaster recovery sites must be established in a separate location from the primary location, and have the appropriate infrastructure needed.
e) Standardized naming procedure must be produced.
f) Information must be retained for no longer than its necessity.

- *Removable Media Policy*

a) Removable media on which information is stored (e.g., CD, USB, DVD, printed papers) must be controlled and physically protected with their classification, to protect the information from unauthorized disclosure, modification or destruction.
b) USB ports shall be disabled on all user desktops and workstations, and only enabled based on business requirements. Approvals for enabling the USB and removable media shall be approved by the security officer.
c) Removable media containing ICET confidential data shall not be taken off-site unless prior agreement. Confidential data shall be encrypted (Oracle Database encryption research APPENDIX A)
d) Attempting to install applications from removable media onto any ICET computer assets is prohibited unless authorized by security officer.

- *Information Exchange Policy*

a) Information systems must provide non-repudiation capability to determine whether a given individual took a particular decision at specific time or not.
b) Sensitive information and classified documents must be excluded from systems which do not provide an appropriate level of protection.
c) The information system must protect the integrity of the transmitted information during information transaction.
d) The information system must terminate an open session at the end of session or after pre-defined time period of inactivity.

- *Patch Management Policy*

a) Checks for new security-related patches and updates that are published via vendor web sites must be made at least once every week (e.g., windows server 2008 patches).
b) Newly released patches, service packs, and hot fixes must be installed on the information systems.

- *Server Access Management Policy*

a) Access to server consoles and operating systems shall be limited to system administrators only. All server administrator accounts shall match with password requirements set by ICET password policy.
b) All non-essential, and defaults users, group, and service accounts must be removed (e.g., Scott/Tiger in oracle).
c) All non-essential services must be removed immediately during installation (e.g., netBios).
d) Administrators are prohibited to share their credentials with anyone.

- *Perimeter Security Controls*

Network shall be protected using a firewall and related technologies so as to enable blocking unwanted traffic:
- Hiding vulnerable systems from the external network.
- Providing logs of traffic to and from the private network.
- Hiding information like system names, network topology, network device types and user ID's from the external network.

- *Routers & Switches Security Policy*

a) All routers and switches shall be configured only by the authorized network administrator.
b) The routers and switches shall be configured in order to reduce the risk by allowing only necessary services.
c) Routers must be placed in temperature and humidity controlled environment.
d) Routers must be powered by an uninterrupted power supply (UPS).
e) ICET shall create individual usernames for all administrators with appropriate privilege levels to enable access to routers and switches.
f) Access Control List (ACL) shall be used to restrict the hosts that are not allowed to access the router.
g) All passwords used in the routers and switches should meet the requirements of the password policy.
h) All the routers must have logon banner stating that the unauthorized access to this network device is prohibited, and there should be explicit permission to access or configure the device.
i) Telnet may never be used across any network to manage a router (unless there is a secure tunnel protecting the communication), SSH is the preferred management protocol.

- *Desktop Security*

a) Users at ICET shall not be given local administration privileges.
b) The use of removable storage shall be prohibited as per Removable Media Policy.
c) All desktop should be running standard password-enabled screen saver.
d) All desktops should be running only ICET standard and licensed software's.

- *Wireless Network Controls*

a) Wireless Access Point (WAP) passwords should not be set to default.
b) SSID name should not be set to default.
c) WEP Encryption should not be used to grant access.
d) Wireless network gateways shall be configured so that they employ firewalls to filter communications with remote devices.
e) MAC filtering should not be used to grant access.
f) Ensure that WAP are secured properly.

- *E-mail Management Policy*

a) E-mail content scanning and spam control must be used to reduce the risk from denial of service attacks (DoS).
b) ICET retains the rights to access employee e-mail if it has reasonable grounds to do so. E-mail content will not be disclosed other than for security purposes.
c) To prevent computer viruses and spams employees are advised not open attachments that are from unknown sources.
d) ICET employees must treat e-mail messages and attachments as confidential information. E-mail must be handled as a confidential and direct communication between both entities sender and recipient.
e) All messages sent by employees by e-mail are the records of ICET. ICET reserves the right to examine emails, personal file directories, and other information stored on ICET computers and servers. E-mail messages may be monitored for many reasons such as supporting internal investigations for suspected criminal activity or fraud.
f) Offensive e-mails must be reported directly to the security officer.
g) Users should not use their official e-mail ID to subscribe to news groups that generate heavy amount of mail traffic.
h) E-mail signature for ICET shall be standardized.

3.2.9. Access Management Policy

The objective of access management is to ensure good management of users' identities, and granting access to these users.

- *User Access Management Policy*

a) All employees must sign the acceptable use statement before being granted system access.
b) Allocation of user privileges must be controlled.
c) User access rights must be reviewed regularly to very ICET access control policies.

- *Password Policy*

a) Users must not share passwords.
b) Passwords are a must requirement for all accounts.
c) Forgotten passwords must be managed in a secure manner.
d) Passwords provided through a procedure, that involved third party knowledge (e.g., doctors to student password delivery techniques), must require the password's owner to change it at first use.
e) Passwords must have a defined expiry period which depends on the sensitivity of the accounts.
f) Passwords must contain at least one numeric or special character.
g) Password must contain a mixture of at least one uppercase and at least one lowercase letter.
h) Passwords must not be displayed in clear text as they are being typed.
i) Authentication mechanism must be done in a secure manner to ends, end-user and authenticator.

- *Lockout Policy*

a) Inactive terminals, which serve high-risk services, must shutdown after a defined period of inactivity to prevent access by unauthorized person.
b) The time-out procedure must clear the terminal screen and close both the application and network sessions after pre-defined period of inactivity.
c) Restrictions on connection times must be considered to provide additional security for applications. (E.g. brute force attacks).

- *Network Security Policy*

a) Users must only have access to the services that they have been authorized to.

b) All methods of remote access to the information system must be documented, monitored, including remote access for privileged functions.
c) Users are prohibited from attaching modems directly to their computers.
d) Access to all external networks must pass through and access control point (e.g. firewall) before reaching and intended hosts.
e) All information must be transmitted in an encrypted format. Including wireless local area networks (LANs), all protocols must be encrypted (e.g. HTTPS).
f) Only authorized and approved network devices may be connected to the network.
g) Use of unencrypted passwords to access network devices internally or externally is prohibited.
h) Network monitoring mechanisms must be active to detect, record, and prevent network hacking attempts and denial of service attack (DoS).
i) All network management passwords must be changed based on password policy.

- *Encryption Policy*

a) Encryption must be considered for the protection of information processing which is categorized as moderate or high classification.
b) An appropriate cryptography technique/algorithm must be implemented taking into consideration the needed protection, implementation and key management.
c) Care must be taken to protect confidentiality of the private key, which must be kept secret.
d) Protecting the public key is mandatory by using public key certificate.
e) Non-repudiation services must be used where it is necessary to resolve any misunderstanding about event occurrences.
f) To reduce the risks of compromise of cryptographic keys, a management system must be in place to support the ICET use of two cryptographic techniques:

- Private Key technique, where two or more entities share the same key for encryption and decryption. This key must be secret since anyone have access to it would be able to decrypt information uses encrypted by this key. This technique could be used for encryption of Database columns for access control needs.
- Public Key techniques, where each user has pair of keys. A public which is revealed to everyone and private which is secret. Private keys must be protected from any unauthorized disclosure.

3.2.10. Business Continuity Management Policy

The purpose of business continuity management is to create a practiced plan for how the ICET will recover within a specific time period after a disaster or disruption.

a) Business continuity plans must be established.
b) Each business continuity plan must clearly specify the conditions for its activation.
c) Each plan must have a specific owner.
d) Emergency procedures must take place in every plan and must be within the responsibility of the owner of the plan.
e) Business continuity plans may fail upon being tested, usually due to incorrect assumptions or change in equipment's or employees. They must therefore be tested regularly to ensure that they are up-to-date and effective. Such tests must ensure that all members of the recovery team and all ICET staff are aware of the plan.
f) Test schedule must be established, which ensures that the plan(s) will operate in real life.

3.2.11. Acceptable Use Policy

ICET must specify the acceptable use of every information system assets, in which all asset end users must be documented.

3.2.12. Risk Assessment and Risk Mitigation Plan

An excel sheets for the plan have been developed and submitted to the ICET center. It should be noted that due to the size (many pages) of the excel sheets; we have excluded them from this paper. However, they are available upon request.

4. Summary and Conclusions

Security breaches have been addressed as a major threat for organizations around the world. Organizations and governments spend millions of dollars annually to recover from attacks' negative impact on their information assets. Many statistics have stated that most of the security breaches caused by an internal organization problem or can be prevented by eliminating an internal problem. Hence, information security management systems are being adopted by many organizations in order to have appropriate controls to eliminate possible internal organizational problems that may introduce some serious security breach. In this paper, we have taken HU as a case study (most of Jordanian universities have similar IT setup) and it is concluded that Jordanian universities information systems are facing real possible dangerous security breaches due to the presence of a huge number of different kinds of vulnerabilities in their information systems. The vulnerabilities can be categorized as:

- Inadequate information security awareness for the organization personnel.
- Organizations do not adopt an information security management system to control the security process of the information systems.

We have presented a full package solution for different kinds of vulnerabilities whether technical or organizational by implementing ISO27001 information security management system ISMS, which should eliminate all the vulnerabilities identified during vulnerabilities assessment phase. The main focus was to identify the risks in Jordanian universities' information systems as well as planning for implementing ISO27001 by developing the needed controls. Hence, it enables Hashemite University to start the stages of eliminating the identified risks. With the introduction of these procedures and documents, the Hashemite University will be ready to start the **Do stage,** which is applying the ISMS on the ICET toward getting an ISO accreditation.

References

[1] Jacobs, S., Security Management of Next Generation Telecommunications Networks and Services, Wiley-IEEE Press, 2014

[2] ISO/IEC, "Information technology-Security techniques-Information security risk management", ISO/IEC 27005:2011, 2011.

[3] Tipton, Harold F. and Micki K., Information Security Management Handbook, 4th Edition. New York: Auerbach Publications, 2000.

[4] Donald Waters. Supply Chain Risk Management: Vulnerability and Resilience in Logistics, 2nd Edition. London, UK, Kogan page, 2011.

[5] G. N. Ericsson, "Cyber security and power system communication—Essential parts of a smart grid infrastructure", *in* IEEE Transaction. Power Del., vol. 25, no. 3, pp.1501 -1507, 2010

[6] Shakeel Ali, Heriyanto Tedi, "Master the art of penetration testing with BackTrack", BackTrack 4: Assuring Security by Penetration Testing, 2011.

[7] British standards (BS) ISO/IEC 27001:2005, British standards (BS) ISO/IEC 27002:2005.

[8] C. Alberts and A. Dorofee, "Managing information security risks: The OCTAVE SM approach". Boston: Addison-Wesley Anderson, 2002.

[9] Moyo, M. ; Abdullah, H. ; Nienaber, R.C., "Information security risk management in small-scale organisations: A case study of secondary schools computerised information systems" *in Proc*. of Information Security for South Africa, pp. 1-6, 2013

[10] Zain-jordan sustainability report 2010, http://www.zain.com/media/social_responsibility/zain-sustainability-report-english_1.pdf, (accessed Feb 2013)

[11] R. Munir, A. Alhomoud, J. P. Disso, and I. Awan, "On the Performance Evaluation of Intrusion Detection Systems," *in Proc*. of Advances in Security Information Management: Perceptions and Outcomes, pp. 117-138, 2013.

[12] Vogt, M., Hertweck, D. Hales, K. Strategic ICT Alignment in Uncertain Environments: An Empirical Study in Emergency Management Organizations, *in Proc.* 44th Hawaii International conference on System Sciences (HICSS), pp. 1-11, 2011.

[13] H. Kumamoto, and E. J. Henley Probabilistic Risk Assessment and Management for Engineers and Scientists, Wiley-IEEE Press, 2000.

المملكة الأردنية الهاشمية

الجامعة الهاشمية

المجلة الأردنية
للهندسة الميكانيكية والصناعية

JJMIE

مجلة علمية عالمية محكمة

تصدر بدعم من صندوق البحث العلمي

http://jjmie.hu.edu.jo/

ISSN 1995-6665

المجلة الأردنية للهندسة الميكانيكية والصناعية

مجلة علمية عالمية محكمة

المجلة الأردنية للهندسة الميكانيكية والصناعية: مجلة علمية عالمية محكمة تصدر عن عمادة البحث العلمي و الدراسات العليا في الجامعة الهاشمية بالتعاون مع صندوق دعم البحث العلمي في الأردن.

ترسل البحوث إلى العنوان التالي

رئيس تحرير المجلة الأردنية للهندسة الميكانيكية و الصناعية

عمادة البحث العلمي والدراسات العليا

الجامعة الهاشمية

الزرقاء - الأردن

هاتف : 3903333 5 00962 فرعي 4147

Email: jjmie@hu.edu.jo

Website: www.jjmie.hu.edu.jo