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Journal of Loss Prevention in the Process Industries 16 (2003) 235–241

Journal of Loss Prevention in the process industries

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Calculation of Fire and Explosion Index (F&EI) value for the Dow Guide taking credit for the loss control measures

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Abstract

The Dow Fire and Explosion Index (F&EI) is universally used in evaluating the hazard category of a process plant, area of exposure, expected losses in case of fire and explosion, etc. In the current procedure, the effects of the loss control measures (LCMs) on the F&EI value are not taken into account. This makes the plant look more hazardous, makes it more spread out, requires more elaborate emergency measures and alarms the public and the civil administration more than is necessary. It also affects the insurance premium.

We suggest taking the effects of the LCMs into account in the F&EI value. We call this the 'Offset F&EI' value. It favorably affects all the above items, and other related ones. To do this, we have developed the relevant equations and have proved the efficacy of the Offset F&EI by means of an example.

Keywords: Fire and Explosion Index; Dow Index; Dow Guide; Hazards; Process safety

1. Introduction

The fire and explosion potential of any large chemical plant, specially those processing/storing hydrocarbons, is enormous. When that potential materializes, it leads to loss of life, serious injuries, huge financial losses due to equipment damage and production interruption, job losses to the workers and permanent damage to the environment (Coco, 1998). In order to be forewarned about such a devastating potential, many process plants use either the Dow Fire and Explosion Index Hazard Classification Guide (henceforth, Dow Guide) (Dow, 1994) or the Mond Fire, Explosion and Toxicity Index (henceforth, Mond Guide) (Mond, 1993) to calculate a Fire and Explosion Index (F&EI). While the Mond Guide is more elaborate, accounts for several extra features and can also be used to estimate the effects of various safety and preventive measures (called the loss control measures, LCM), its use is not very widespread. This could be due to its elaborate worksheets requiring more effort and lack of knowledge amongst professionals about its special features. The Dow Guide, on the other hand, is used worldwide. It is also the focus of this paper.

A lot of effort has gone into preparing the Dow Guide by the Dow Chemical Company and in popularizing it by the American Institute of Chemical Engineers. Our effort has been to make it more dynamic and responsive to the emerging situation worldwide. In an earlier paper (Gupta, 1997), we had suggested enhancements in several penalty values for use in developing countries because the ground realities there are very different than in the developed countries where the Dow Guide originated and where it is periodically updated. In this paper, we suggest a modification in the calculation of the F&EI so as to bring upfront the effects of the LCMs. As will be pointed out, this works in favor of the process industry and may help improve its public image.

2. The details

Currently, in the Dow Guide, the F&EI is calculated without considering the LCMs (Fig. 1, Dow, 1994). This

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0950-4230/03/$ - see front matter © 2003 Elsevier Science Ltd. All rights reserved.
doi:10.1016/S0950-4230(03)00044-5

Nomenclature

AEO	area of exposure
BI	business interruption
C_1	process control credit factor
C_2	material isolation credit factor
C_3	fire protection credit factor
DF	damage factor
F_1	general process hazard penalties
F_2	special process hazard penalties
F&EI	Fire and Explosion Index
GPH	general process hazards
LCCF	loss control credit factors
LCMs	loss control measures
MF	material factor
MPDO	maximum probable days outage
MPPD	maximum probable property damage
RV	replacement value
SPH	special process hazards
VPM	value of production per month

Subscripts

1	Value as per the existing procedure
2	New values related to Offset F&EI

F&EI value is then used to look up the relative hazard rating given in Table 1 (Dow, 1994). F&EI is also used to determine the radius of exposure (ROE), the area of exposure (AOE), the replacement value (RV) of equipment in AOE and the base maximum probable property damage (Base MPPD). It is at this point that the effect of LCMs, known as loss control credit factor (LCCF), is incorporated to calculate the actual MPPD. The LCCF is not used to see its effect on F&EI, which would in turn reduce the hazard rating, AOE, replacement value of equipment within AOE, etc.

In this paper, we suggest the inclusion of the effects of LCMs (i.e., LCCF) on F&EI itself. It gives a clearer picture of the favorable effects of LCMs and hence justification of their cost. It works in favor of the plant management, operators, habitation nearby and the civic authorities by giving them a more realistic picture of the hazard rating and the expected area of exposure. It also might help improve the public perception of the chemical process industry. We call this new F&EI, the 'Offset F&EI' for the purposes of discussion in this paper. We first develop the equations and procedure to calculate the Offset F&EI and then compare it with the existing F&EI using an example of ammonia synthesis reactor. This will show the advantages of our suggested approach. While the idea of Offset F&EI exists in the Mond Guide, the procedure suggested here for the Offset F&EI for the Dow Guide is very different. As we develop the procedure, the final relation needed is given in Eq. (6) below. The modified line diagram for the use of Dow Guide is given after the example, in Fig. 4.

Table 1
Hazard ratings (Dow, 1994)

F & E Index range	Degree of hazard
1–60	Light
61–96	Moderate
97–127	Intermediate
128–158	Heavy
159–up	Severe

3. Procedure

The Dow Guide procedure (Fig. 1) gives

a. $$\text{Actual MPPD} = \text{Base MPPD} \times \text{LCCF} \tag{1a}$$

or

$$\text{LCCF} = \frac{\text{Actual MPPD}}{\text{Base MPPD}} \tag{1b}$$

Further

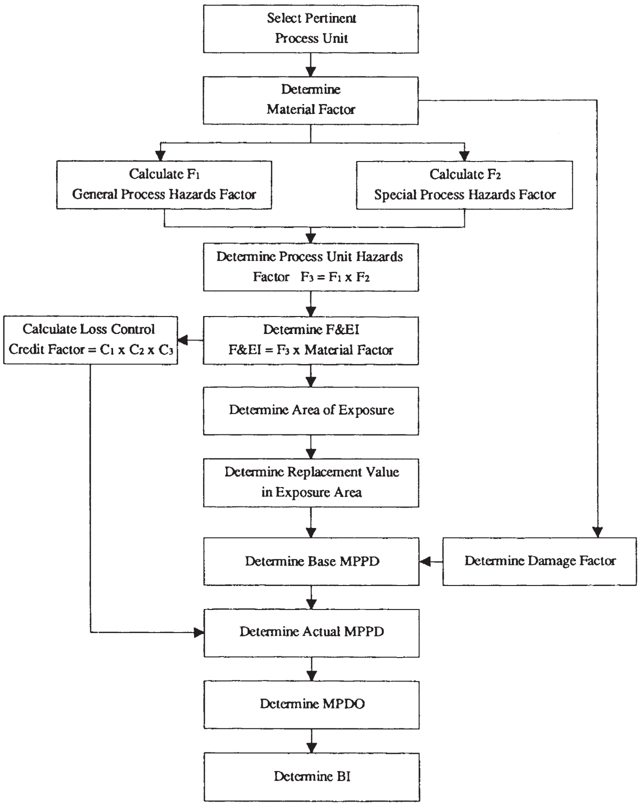

Fig. 1. Procedure for calculating fire and explosion index and other risk analysis information (Dow, 1994).

b. Base MPPD $=$ DF $\times$ (2a)

Replacement value of equipment located in the AOE

where DF is damage factor
Since the ROE = 0.84 F&EI (Fig. 7, Dow, 1994)
Hence,

$$\text{AOE} \propto (\text{radius of exposure})^2 \propto (\text{F\&EI})^2 \tag{2b}$$

Putting Eq. (2b) into Eq. (2a), gives
Base MPPD$\propto$DFx(F&EI)^2
Hence, we can write

$$\frac{\text{Base MPPD}_2}{\text{Base MPPD}_1} = \frac{(\text{F\&EI}_2)^2}{(\text{F\&EI}_1)^2} \tag{3}$$

where Subscript 1 = values as per the existing Dow Guide procedure, 2 = new values related to Offset F&EI. DF remains unchanged since it depends only on the material factor (MF) and process unit hazard factor (F_3, Fig. 2). It gets cancelled in Eq. (3).

The effect of LCCF on Base MPPD$_1$ is to give actual MPPD$_1$ (Eq. (1a)). The effect of LCCF on F&EI$_1$ in our suggested modification is to give the proposed 'Offset F&EI' or F&EI$_2$. This is then used to calculate the Base MPPD$_2$, which would be the same as the actual MPPD$_1$, as we will demonstrate with an example.

Hence,

$$\text{Base MPPD}_2 = \text{Actual MPPD}_1 \tag{4}$$

Replacing this in Eq. (3) and using Eq. (1b), we get

$$\frac{\text{Actual MPPD}_1}{\text{Base MPPD}_1} = \text{LCCF} = \frac{(\text{F\& EI}_2)^2}{(\text{F\& EI}_1)^2} \tag{5}$$

Hence,

$$\text{F\&EI}_2 = (\text{LCCF})^{1/2} \times (\text{F\&EI}_1) \tag{6}$$

The F&EI$_2$ is the Offset F&EI proposed in this paper.

4. Example: ammonia synthesis reactor

The Dow F&EI form and LCCF form for this example are in Figs. 2 and 3, respectively (Blank forms, Dow, 1994). Readers may assign somewhat different values but those differences are not important to show the concept of the Offset F&EI.

The values of interest from Fig. 2 are:

MF = 21

$F_1 = 1.5$

$F_2 = 5.13$

$F_3 = 7.7$

F&EI$_1$ = 161.7

This is ranked as severe hazard (Table 1).

In LCCF (Fig. 3), middle values have been chosen for items that apply and 1.0 for those that do not apply. Readers may choose other values but that will not affect the concept of Offset F&EI being presented here. Fig. 3 gives LCCF = 0.4793

The process unit risk analysis summary, as per the current procedure, has been filled in at the bottom of Fig. 3. The value of AOE, also called the RV, has been calculated by multiplying the AOE with an assumed value of \$ 5000/m^2. The Dow Guide (Dow, 1994, p. 51) recommends:

$$\text{RV} = \text{Original cost} \times 0.82 \times \text{Escalation factor}$$

For our discussion purposes here, we have taken 0.82 $\times$ escalation factor = 1.

5. Calculation of Offset F&EI (F&EI$_2$)

Eq. (6) gives F&El$_2$ = $(0.4793)^{1/2} \times 161.7 =$ 111.947. This is over 30% less than the original F&EI$_1$ and lies near the middle of the intermediate hazard range (Table 1). This is a significant decrease in the hazard rating which has come down from a rating of 'severe' to 'intermediate' leaving also the rating of 'heavy' hazard in between. AOE and RV also get reduced significantly. This, we assert, is the real F&EI value, after tak-

FIRE & EXPLOSION INDEX

AREA / COUNTRY	DIVISION	LOCATION	DATE
SITE	MANUFACTURING UNIT	PROCESS UNIT Ammonia Synthesis Reactor	
PREPARED BY:	APPROVED BY: (Superintendent)	BUILDING	
REVIEWED BY: (Management)	REVIEWED BY: (Technology Center)	REVIEWED BY: (Safety & Loss Prevention)	

MATERIALS IN PROCESS UNIT Hydrogen, Nitrogen, Ammonia

STATE OF OPERATION: __ DESIGN __ START UP __ NORMAL OPERATION __ SHUTDOWN

BASIC MATERIAL(S) FOR MATERIAL FACTOR: Hydrogen

MATERIAL FACTOR (See Table 1 or Appendices A or B) Note requirements when unit temperature over 140 °F (60 °C)		21
1. General Process Hazards	**Penalty Factor Range**	**Penalty Factor Used(1)**
Base Factor	1.00	1.00
A. Exothermic Chemical Reactions Hydrogen	0.30 to 1.25	0.30
B. Endothermic Processes	0.20 to 0.40	
C. Material Handling and Transfer	0.25 to 1.05	
D. Enclosed or Indoor Process Units	0.25 to 0.90	
E. Access	0.20 to 0.35	0.20
F. Drainage and Spill Control ______ gal or cu.m.	0.25 to 0.50	
General Process Hazards Factor (F_1)		1.50
2. Special Process Hazards		
Base Factor	1.00	1.00
A. Toxic Material(s) Due to ammonia, N(H) = 3	0.20 to 0.80	0.60
B. Sub-Atmospheric Pressure (< 500 mm Hg)	0.50	
C. Operation In or Near Flammable Range ___ Inerted ___ Not Inerted		
1. Tank Farms Storage Flammable Liquids	0.50	
2. Process Upset or Purge Failure	0.30	0.30
3. Always in Flammable Range	0.80	0.80
D. Dust Explosion (See Table 3)	0.25 to 2.00	
E. Pressure (See Figure 2) Operating Pressure ______ psig or kPa gauge; Relief Setting ______ psig or kPa gauge		0.93
F. Low Temperature	0.20 to 0.30	
G. Quantity of Flammable/Unstable Material: Quantity ____ lb or kg; H_C = ____ BTU/lb or kcal/kg		
1. Liquids or Gases in Process (See Figure 3)		1.40
2. Liquids or Gases in Storage (See Figure 4)		
3. Combustible Solids in Storage, Dust in Process (See Figure 5)		
H. Corrosion and Erosion	0.10 to 0.75	0.10
I. Leakage – Joints and Packing	0.10 to 1.50	
J. Use of Fired Equipment (See Figure 6)		
K. Hot Oil Heat Exchange System (See Table 5)	0.15 to 1.15	
L. Rotating Equipment	0.50	
Special Process Hazards Factor (F_2)		5.13
Process Unit Hazards Factor (F_1 x F_2) = F_3		7.7
Fire and Explosion Index (F_3 x MF = F&EI)		161.7

(1) For no penalty use 0.00.

Fig. 2. Ammonia synthesis reactor.

ing into account the LCCF. After all, the loss control measures are installed to reduce the hazard potential of a process which also justifies their cost. Hence, their effect ought to be considered in the calculation of the F&EI itself since it affects the later calculations.

The process unit risk analysis summary (Fig. 3) would get modified to reflect the use of F&EI_2 (Table 2). Comparing it with the one as per the existing procedure (Fig. 3, bottom), gives the benefits that accrue to be:

- The radius of exposure has been reduced by about 30%, from 41.4 to 28.66 m, and the area of exposure by 52%, from 5384 to 2580 m^2 (Fig. 5). Hence, the domino effect will not have a far reach of 41.4 m as predicted by the existing procedure. The equipment will therefore be less spread out to save from the domino effect. This implies lesser land requirement, shorter pipe lengths, lesser number of flanges, lower pressure drop and energy losses. This makes the system cheaper and inherently safer as well since there are lesser number of flanges to leak.
- The ROE being shorter would also imply lower insurance premium, less fire water requirement, less tense workers, management and the civic authorities.
- The actual MPPD, MPDO and business interruption (BI) have remained unchanged between the two procedures, which confirms that the method suggested is a sound one since it does not reduce the net financial consequences of the hazard materializing, it reduces significantly the impact or exposure area with its consequential benefits.

6. Modified procedure for F&EI and other risk analysis information

In calculating the F&EI_2 value above, use has already been made of LCCF. Hence, there is no need to calculate

1. Process Control Credit Factor (C_1)

Feature	Credit Factor Range	Credit Factor Used (2)	Feature	Credit Factor Range	Credit Factor Used (2)
a. Emergency Power	0.98	0.98	f. Inert Gas	0.94 to 0.98	1.00
b. Cooling	0.97 to 0.99	0.98	g. Operating Instructions/Procedures	0.91 to 0.99	1.00
c. Explosion Control	0.84 to 0.98	0.91	h. Reactive Chemical Review	0.91 to 0.98	0.95
d. Emergency Shutdown	0.96 to 0.99	0.98	i. Other Process Hazard Analysis	0.91 to 0.98	0.95
e. Computer Control	0.93 to 0.99	0.96			

C_1 Value (3) 0.742

2. Material Isolation Credit Factor (C_2)

Feature	Credit Factor Range	Credit Factor Used (2)	Feature	Credit Factor Range	Credit Factor Used (2)
a. Remote Control Valves	0.96 to 0.98	0.97	c. Drainage	0.91 to 0.97	0.94
b. Dump/Blowdown	0.96 to 0.98	1.00	d. Interlock	0.98	1.00

C_2 Value (3) 0.9118

3. Fire Protection Credit Factor (C_3)

Feature	Credit Factor Range	Credit Factor Used (2)	Feature	Credit Factor Range	Credit Factor Used (2)
a. Leak Detection	0.94 to 0.98	0.96	f. Water Curtains	0.97 to 0.98	1.00
b. Structural Steel	0.95 to 0.98	0.97	g. Foam	0.92 to 0.97	1.00
c. Fire Water Supply	0.94 to 0.97	0.96	h. Hand Extinguishers/Monitors	0.93 to 0.98	0.96
d. Special Systems	0.91	1.00	i. Cable Protection	0.94 to 0.98	0.96
e. Sprinkler Systems	0.74 to 0.97	0.86			

C_3 Value (3) 0.7085

Loss Control Credit Factor = C_1 X C_2 X C_3(3) = 0.4793 (Enter on line 7 below)

PROCESS UNIT RISK ANALYSIS SUMMARY (current procedure)

1. Fire & Explosion Index (F&EI)	(See Front)	161.7	
2. Radius of Exposure	(Figure 7)	41.4 m	
3. Area of Exposure		5384.564 m^2	
4. Value of Area of Exposure ($5000/ $m^{2)}$			$MM 26.9228
5. Damage Factor	(Figure 8)	0.83	
6. Base Maximum Probable Property Damage – (Base MPPD) [4x5]			$MM 22.3459
7. Loss Control Credit Factor	(See above)	0.4793	
8. Actual Maximum Probable Property Damage – (Actual MPPD) [6x7]			$MM 10.7104
9. Maximum Probable Days Outage (MPDO)	(Figure 9)	86.15 days	
10. Business Interruption – (BI) (VPM = $MM 100)			$MM 201.017

(2) For no credit factor enter 1.00. (3) Product of all factors used.
Refer to *Fire & Explosion Index Hazard Classification Guide* for details.

Fig. 3. Loss control credit factors (Dow, 1994).

the Base $MPPD_1$ and actual $MPPD_1$. The replacement value (RV_2) in AOE_2 is the actual value of the expected property damage when $F\&EI_2$ is used. This appears more logical too instead of having to modify the RV_1 by DF to calculate the Base $MPPD_1$ and then by LCCF to get the actual $MPPD_1$, as in the existing procedure. From the actual RV_2 one can calculate the actual MPPD and then the MPDO using Fig. 9 in the Dow Guide (Dow, 1994) or the equation given there. The line diagram of the modified procedure is shown in Fig. 4 to replace Fig. 1 in the Dow Guide (Dow, 1994).

7. Advantages of calculating Offset F&EI

- Easier evaluation of cost vs. benefit of different LCMs.
- The net effect of LCMs is seen immediately in the reduction of F&EI and AOE and also on the hazard status of the process unit.
- With F&EI and AOE both reduced, insurance premium will reduce.
- With the AOE reduced, the plant layout can be relatively more compact since the units do not need to be spread out too far to avoid the domino effect.
- In a relatively compact plant, the cost of piping, heat loss and pressure drop through piping, the number of flanges, etc., will reduce. While each of these is a small gain, the total would add up to a significant amount, year after year.
- With a lower Offset F&EI and hence lesser hazard rating (Table 1) and lower ROE (= 0.84 × F&EI), the emergency management plans will become more manageable since there will be a reduction in the on-site and off-site consequences. The management, the staff, the inhabitants nearby and the civic authorities will feel more secure.

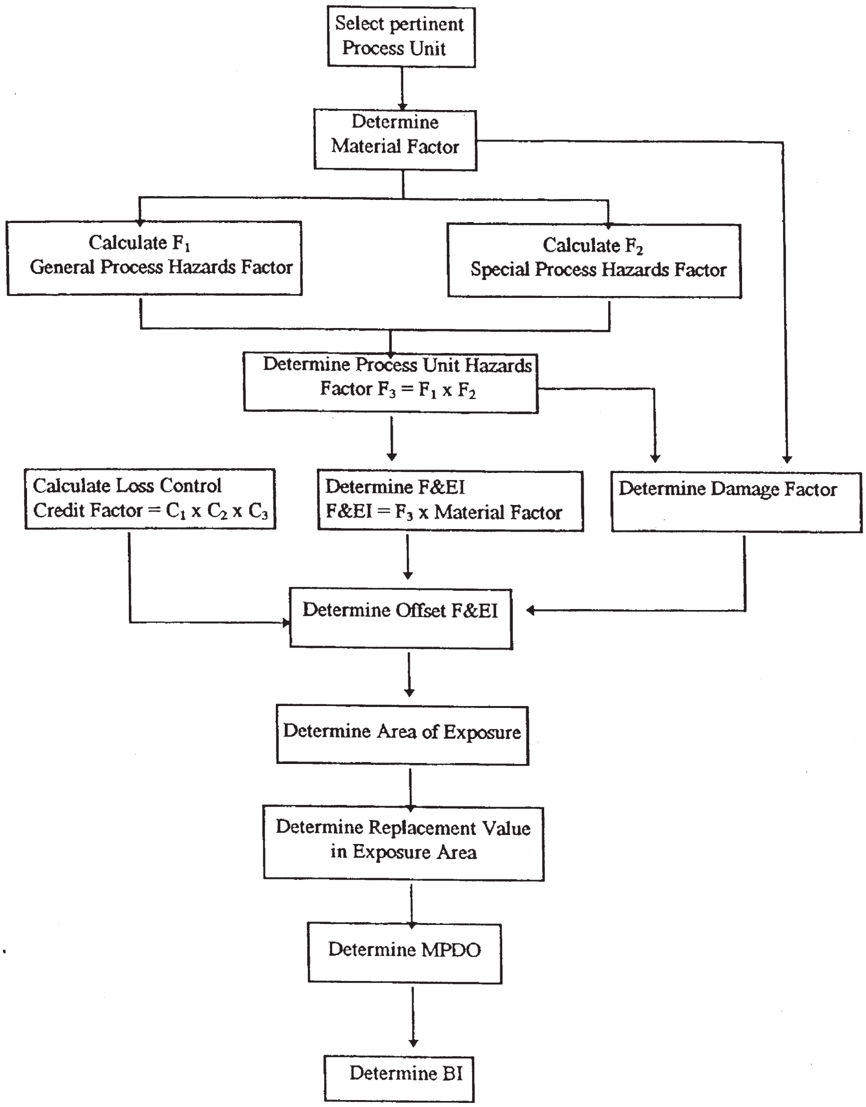

Fig. 4. Modified procedure for calculating fire and explosion index and other risk analysis information.

Table 2
Modified Process Unit Risk Analysis Summary

1	Fire and Explosion Index (F&EI) (see front)	161.7	
2	Loss control credit factor (LCCF) (see above)	0.4793	
3	$(LCCF)^{1/2}$	0.6923	
4	Offset F&EI ($F\&EI_2$) (1×3)	111.9473	
5	Radius of exposure (Fig. 7)	28.66209 m	
6	Area of exposure	2580.867 m^2	
7	Value of area of exposure (\$ 5000/m^2)		\$ MM 12.904
8	Damage factor (Fig. 8)	0.83	
9	Maximum probable property damage (MPPD) (7×8)		\$ MM 10.7106
10	Maximum probable days outage (MPDO) (Fig. 9)	86.15 d	
11	Business interruption (BI) VPM = 100 \$MM		\$ MM 201.017

- Surveys indicate that the public perception of the safety record of the chemical process industry is worse than is actually the case. Hence, we should not deliberately make it look worse by not accounting for the LCMs in the F&EI value.

8. Conclusions

The calculation of the offset F&EI ($F\&EI_2$) gives a clearer picture of the fire and explosion hazards. There is no need to be extra conservative by having a greater

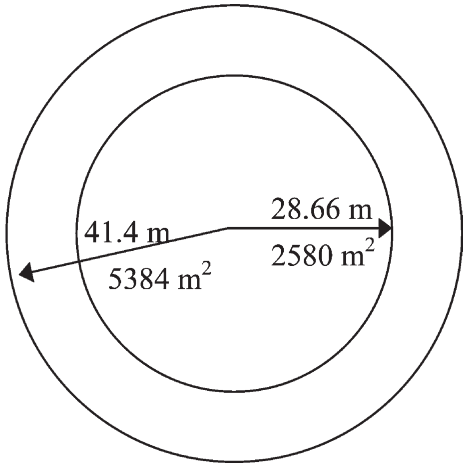

Fig. 5. Radii and areas of exposure for example case, outer circle: as per the existing procedure, inner circle: as per the proposed procedure.

F&EI than is actually the case with the LCMs installed. The calculation and use of the offset F&EI saves on insurance premiums, land cost, piping costs and all the losses associated with longer piping, if equipment is spread out much more than is necessary. It also gives a more realistic picture of the on-site and off-site emergency plans. The modified procedure (Fig. 4) looks more logical with the use of the RV_2 directly to calculate the actual MPPD, MPDO and BI instead of interjecting the further calculation of Base $MPPD_1$. The Offset F&EI brings out more clearly the inherently safer nature of the plant.

The MPPD, MPDO and BI remain the same in both the cases. This implies that the expected losses are confined to a significantly smaller area than the value given by the existing procedure. This also proves the validity of our procedure.

Users of the fifth edition of the Dow Guide would recall that for LCCF, one used to fill a form to get C_1, C_2, C_3 and, using their product one had to read the actual LCCF from Fig. 9 in that edition. In the current edition (Dow, 1994), the values of C_1, C_2, C_3 have been so modified that their product itself gives the value of the LCCF and the earlier Fig. 9 has been dispensed with.

We believe that the result will be similar to the suggestion in this paper to calculate the offset F&EI to get a better idea of the actual F&EI and to use the actual replacement value and thus delete two steps of Base $MPPD_1$ and actual $MPPD_1$ from the calculation of MPDO and BI.

Once the modified procedure, as suggested, is accepted, the subscripts 1 and 2 can of course be dropped and the nomenclature would revert back to the same as in the Dow Guide (Dow, 1994).

With the Base MPPD no longer necessary to calculate, the 'actual MPPD' can be renamed simply as 'MPPD' dropping the prefix 'actual'.

Acknowledgements

Help rendered by Mr. Yashpal and Ms. Keri Kasee in graphics is gratefully acknowledged.

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