!" 004.415(045)

!#%'#) .+ ., #.$.%

-)-/02 357)9/9;0= >?95 3A+-))B
0)D9?E-G0=)H7 IHI35E

&(*+-%(/0%12(3+(*+2%12%+368:1$6$

kirhar@ukr.net

@(3$B "$&$3+ C1/1'-5 >+D$"+E31//?<"$(D3:>1'G/+D1*+ <(>/$73(H/$'$J-7 <"$(D3:>1/ -/?, >-K<$>-K/$1EL31&: 31 E&'+>$E3?*"$5"$&'B>1/J <"$(D3:. "$K:D3+>/-E3G C J$'$>/+* M+//+D$*, N$ >+5/1M1Q0(D3+>/-E3G E+E3(*+. O1"/(<"$(D3/("-L(//? E':-Q+3G $E/$>$B>+E$D$<"$K:D3+>/$E7+E3(*+

KLMNP! QKNP' <8-6#$43(%%=%>-8?(*+2%1:$6?1, $6@%-/-B+C%6(86D(<8-6#$43(%%=<8-6#$

Вступ

E0-B-G%+ 4 3+# +%>-8?(*+H $(#-?<'K$681L(*+H+%>-8?(*+2%86:48:1 M $(#1?1 :(?1?1 86:48:(?1, =# + $84G-3,+?($68+(/0%$(6%68B6$1C%6-D, ?-D/1 -3- 8-LB/=G($1 +%>-8?(*+2%46#-%-?+#,4 P- Q84%$4M$0%(+%>-8?(*+,H$(+%>-8?(*+2%4:>684 – #68+3%1#83L%18@3%,+34C6%1,@<6*+(/+:$+3+:/4DR-3*+3. <8(3 -/+%%=6#-%-?+#-K ?-D%(<-8+3%=$1L 4<8(3/+%%=D131? -8B(%+L?-,? G6B-/- -3%4-/0 3+G+B8%(6683-3(:1:$6?(.

S #8(H%+ <8-*6: +%>-8?($1L(*+H LG+2:%KM$0:B+G%L-&(*+-%(/0%-K <8--B8(?-K +%>-8?($1L(*+,H =#(31L%(C(M :$8($6B+K8-L3'=L(%%=<8-R/6?1 L(R6L<6C6%%=%>-8?(*+2%1@$86R$(+%>-8?(*+2%-H<+G$81?#1-*+(/0%- -6#-%-?+C%,-H 6#-/-B+C%,H%(4#-3–$6@%+C%-H-8-%%-,H%(*+-%(/0%-#4/0$48%-H$(+%U-HG+=/0%-:$+ 4 :>68(@ L(B(/0%-G68D(3%-B-L%(C6%%[4].

&(*+-%(/0%(<8-B8(?(+%>-8?($1L(*+H-B1L%(C(H$(#+-:%-3%+%(<8=?1+%>-8?($1L(*+H

– 8-L8-R/6%%=<-/+$1#1 $(-8B(%+L(*+2%-<8(3-3-B- L(R6L<6C6%%=%>-8?($1L(*+,H

– >-8?43(%%=%(*+-%(/0%-H+%>8(:$84#$481+%>-8?($1L(*+,H

– +%>-8?($1L(*+=:$8($6B+C%1@(<8=?+38-L31$#4G68D(3%-:$+R6L<6#1$(-R-8-%1;

– +%>-8?($1L(*+=<8-*6:+3 :-*+(/0 -%–6#-%-?+C%-B-L31$#4;

– +%>-8?($1L(*+=<8+-81$6$%1@(/4L62 6#-%-?+#,1

– +%>-8?($1L(*+=>+%(%:-3-H$(B8–U-3-H :1:$6?1, G68D(3%-B->+%(%:-3-6#-%-?+C%-B-%$8-/K;

– +%>-8?($1L(*+=*+(/0%-H:>681;

– +%>-8?($1L(*+=3 B(/4L+6#-/-B+H$(31#-81:$(%%=<818-G%1@6:48:+3;

– +%>-8?($1L(*+=%(4#1 -:3+$1 +#4-/0$481;

– ?+D%(8-G%6+38-R+$%1*$[4].

N:%-3%1?1%-8?($13%1?1(#$(?1 4*+2:>68+M V(#-% #8(H%1«W8- +%>-8?(*+K», «W8- %(*+-%(/0%4<8-B8(?4 +%>-8?($1L(*+H, «W8- 6/6#$8-%%12>1>8-312<+G<1», «W8- 6/6#$8-%%6G-#4?6%$1$(6/6#$8-%%12G-#4?6%$--R», «W8- L(@1:$+%>-8?(*+H 3 +%>-8?(*+2%-$6/6#-?4%+#(*+2%1@$6?(@».

W8-6#$43(%%=%>-8?(*+2%1@1:-$6? (YE, =3/=M:#/(G%12 R(B($-:$4<+%G(:$12 31GG+=/0%-:$+R6L%(4#-3-H8B(%+L(*+H-#-B- %6?1:/1?6 :$3-86%%=31#-81:-$(%%=4C(:%1@#/(G%1@YE, 4 $-?4 C1:/+3 -:3+$, <+G<81M?%1*,$36%6GD?6%$(++%U1@R/(:$=@D1$$MG+=/0%-:$+<+/0:-$3(. W-8=GL -$81?(%%=?%6-R@+G%G1@*0-B- $6-86$1C%1@(%%<8-6#$43(/0%1#4 YE<-$8+R%LG-R4$1:$+2#+<8(#$1C%+%(31C#10-B- 31G4G+=/0%-:$+

Постановка проблеми

W8-6#$43(%%=%>-8?(*+2%1@1:-$6? L(3DG1<-C1%(M$0:L=31L%(C6%%6=

$1 <8-6#$4 N:%-3%6L(3G(%%R4G0=#-B-4:<+U%-B-<8-6#$4 <-/=B(M 3 $-?4, P-R %(?-?6%$ L(<4:#4 :1:$6?1 + <8-$=B-?4:0-B- C(:4 H6#:</4($(*+H?-D%(R4/-L(R6L<6C1$1

– %6-R@+G%4%#*+-%(/0%+:$0: -$6?1+:$4<+%0G(<$(*+HG- ?+%/131@?-3 H4%#*+-%43(%%=

– %6-R@+G%8-<4:#%4 LG($%+:$0 :1:$6?1;

– %6-R@+G%C(86(#*+H:1:$6?1 %(L(<1$

– R6L3+G?-3%4R-$4:1:$6?1 3 %6-R@+G%-86D1?+%U1?1/-3(?1 - B– $-3%+:$0G-:$4<%+:$0:1:$6?1 G/=-R8-R-#1 L(<1$+3#-81:$43(C+3

– <8-:$-$4 6#:</4($(*+H+<+G$81-?#1:1:$6?1;

– %6-R@+G%R6L<6#4

W8-G4#$13%+:$0B-/-3%1? C1%%1#-?, P- 31L%(C(M>6#$13%+:$0:1:$6?1. [(8%6<8-6#$%6+U6%%4D1$0 -:%-3-K 31:-#-<8-G4#$13%-H:1:$6?1.

Аналіз останніх досліджень

W812%=$1368@-3%-K(G-K #8(-H%1V(#-%«W8- -:%-3%+<81%*1<18-L31$#4 +%>-8?(*+2%-B:4:<+/0:$3(3 #8(H%+%(2007-20158-#1» L($368G1&(*+-%(/0-%4 :$8($6B+K8-L31$#4 +%>-8?(*+2%-B-:4:<+/0:$3(3 #8(H%+^%(/+L*0-B- L(#--%4 <-#(L(3, P- «<812%=$$=<-/+$1C%-H<8-<-L1*+H$("-%*6<*+H%6 3+G<-3+G(M-%-3%+26$+G68D(3%-H/+$1#1 #8(H%14:>68+ +%>-8?($1L(*+H$-R$- :<81=%%K<-R4G-3+:4C(:%-H81%#-3-H6#-%-?+#13%(U+2G68D(3+L(R6L<6C6%%KG31P6%%=H#-%#486%$-:<8-?-D%-:$U/=@-? 3<8--3(GD6%%4C(:%1@$(<68:<6#$13%1@0%>-8?(*+2%--#-?4%+#(*+2%1$6@%-/-B+24:+ :>681 D1$$MG+=/0%-:$4#8(H%:0#-B-:4:<+/0:$3(, L 48(@43(%%=?86(/0%-B-:$(%4 2-B- 8-L31$#4, ($(#-D B-$-3%-:$+$(:<8-?-D%-:$+ B8-?(G=%G- 3<8-3(-GD6%%*1@$6@%-/-B»2[4].

86(/0%1@4?-3(@<8-6#$43(%%=*6 <-U4# :<-:-R4, =#12 L(G-3-/0%=M31-?-B(? >4%#*+-%(/0%-:$+1:$6?1 L(:-R(-?1 %(=3%1@6@%-/-B+248(@43(%%±?-G(%1@R?6D6%0

!- R4G0=#-B-<8-6#$4<86G=3/=M$0:= 8=G(R:-/K$%1@31?-B, %(<81#/(G?(#-:1?(/0%12 C(: 8-L8-R#1<8-6#$4 ?(#:1-?(/0%+B8-U-3+3#/(G6%%3<8-6#$+$.GNG%(L+:#/(G%-:$62 <8-6#$43(%%<-/=-B(M3 $-?4, P- 3-%-%6M$(#1?:$84#$48–3(%1?L(3G(%%;?#(%(/+L31?-B G- <8--6#$4(R- 86(/+L(*+H$-B- C1+%U-B<8-6#-$%-B-8+U6%%=

S3(D(M$0:;= P- :#/(G%4 :1:$6?4%6?-D/13- -<1:($1 3 <81%*1<+NG%1?L-:%-3%1@(8B4?6%$+H3L?+%(4?-3 >4%#*+-%43(%%=1:$6?1, %(<81#/(G G186#$13%4L?+%4$1@C1+%U1@$-#+3+%>-8?(*+H%-31? #68+3%1*$3-?`6 -G1%(8B4-?6%$– -R:=B1$6@%+C%=B3G(%%;=#+G/= 36/1#-B- <8-6#$4?-D4$0 :$(%-31$1:-$%+:$-8+%-#3 $-2 C(: =# $6@%+C%12<8-6#$?-D6 ?+:$1$1<-?1/#1. S1%1#(M<1$(%%=(?-D6, #8(P6 3L(B(/+%6<8-3--G1$1-R:$6D6%%=%68-R1$1%+=#-B$6@%+C%-B<8-6#$4(<1:($1 :1:$6?4 "L C1:-$-B- /1:$(" 3 %(G+H($6, P- :$(%6$0:==#12:0C4G6:%12R+B(C6%%L=(?-3%1#(L$1?, P- %(<1:(/1 <8-B8(?+:$1($(#-D %($6, P- 3:6*6 R4G6$(R+/0%-<8(*K3($1?

Мета роботи

VG+2:%6%%8=6#$43(%%¥E<81<4-:#(M 31#-81:$(%%= <8-6#$43(/0%1#(?1<63%-H$6@%-/-B+<8-6#$43(%%;3+G<-3+G%-?(:U$(R4 $(-:-R/13-:$=? 8-L8-R/K-3(%-B-<8-6#$4

W86G?6$-?R4G0=#-H31R18(%-H$6-@%-/-B+<8-6#$43(%%<-31%%-:/4D1$13+G-R8(D6%%3L(M?-<-3=L(%1@<8-*6:+3<8-6#$43(%%%(3:+@:$(G+=@D1$$M3-B-*1#/4 YE!- -:%-3%1@31?-B, P- <86G=3-/=K$0:= $6@%-/-B+<8-6#$43(%%;3+G%-:=$0:=%(:$4<%+

– :$3-86%12<8-6#$<-31%6%3+G<-3+G($31?-B(? L(?-3%1#(;

– ?(#:1?(/0%6 3+G-R8(D6%%3=+@6$(<+3D1$$M3-B*1#/4 <8-6#$4;

– L(R6L<6C6%%=%+?(/0%1@84G-31@+3(8$+:%1@1$8($%(<8-6#$43(%%=:4<8-3+G<8-6#$4;

– $6@%-/-B+<=31%%(R4$1-:%-3-K L3=L#4?+D <8-6#$43(%%=?:4<8-3-G-?<8-6#$4.

– L8-:$(%%=<8-G4#$13%-:$+<8(*+ <8-6#$43(/0%1#,(

– %(G+2%+:$0-*6:4 <8-6#$43(%%= $(6#:</4($(*+H<8-6#$4,

– <8-:$6 36G6%%<8-6#$%-HG-#4 ?6%$(*+H

Основний матеріал

a6$(:$3-86%%=+%>-8?(*+2%1@: - $6? – 4 B8(%1C%#–8-$#+$68?+%1$3-81- $1 :1:$6?4 -R8-R#1G(%1@#(?(ML(G(%+ :<-D13C+=#-:$+[3]. !- %1@%(/6D($0 >4- %#*+-%(/0%(-3%-$(, :3-MC(:%+:$0>4%# *+-%(/0%(%(G+2%+:$0G(<$13%(%(G+2 %+:$06#-%-?+C%6>6#$13%+:$0

c4%#*+-%(/0%(-3%-$(–*6 3/(:$1 - 3+:$0+%>-8?(*+2%-H1:$6?1, =#(@(8(#$6 81L4M8+36%(3$-?($1L(*+H4<8(3/+%:0#1@ 8-R+$

"-6>+*+M%$4%#*+-%(/0%<H3%-$1

$$K_f = \frac{<_(}{<_.},$$

G6W(– <-#(L%1#1-$81?43(%+(3$-?($1 - L-3(%-; W – L(B(/0%(#+/0#+:$0<-#(L%1- #+3

E3-MC(:%+:$0*6 3/(:$13+:$0 +%>- 8?(*+2%-H1:$6?1, =#(@(8(#$681L4M - D/13+:$0-$81?(%%=(<(8($-? #68+3%1*$ 3(%6-R@+G%%H-8?(*+H

"-6>+*+M%$3-MC(:%-:$+

$$K_c = \frac{\nabla <_{a1} - <_{a2}}{<_{a3}},$$

G6W(1...a3 – #+/0#+:$0<-#(L%1#+,3-$81?(- %1@LL($81?#-K P-G- </(%-3-B- $68?+%4 <-G(%%=

c4%#*+-%(/0%(%(G+2%+:$06 3/(: - $13+:$0+%>-8?(*+2%-H1:$6?1 31#-%43($1:3-H>4%#*+H-R8-R#1G(%1@6 :4#4- <%+:$0%(G+2%-:$6<8-B8(?%-B, +%>-8 ?(*+2%-B-$($6@%+C%1-R6L<6C6%%=

^G(<$13%(%(G+2%+:$0*6 3/(:$1 - 3+:$0+%>-8?(*+2%-H1:$6?1 31#-%43($1 :3-H >4%#*+,H=#P- 3-%1 L?+%KK$0:=3 ?6D(@4?-3, L4?-3/6%1@8-L31$#-? :1: - $6?1#6843(%%=R'M#$(3<8-G-3DL(G(%- B- <8-?+D#4C(:4.

e#-%-?+C%(6>6#$13%+:$0+%>-8?(*+2%-H1:$6?1 31=3/=M$0:=3 <-#8(P6%%+ 6#-%-?+C%1@6L4/0$($+3>4%#*+-%43(%%= -R'M#$,(3 86L4/0$($-8<8-3(GD6%%=+%>- 8?(*+2%-H1:$6?1.

E$3-86%%=+%>-8?(*+2%-H1:$6?1 <686GR(C(0(:$#-312 C1<-3%12<686B/=G ?6$-G+3+L(:-R+3>4%#*+-%43(%%+%>-8 ?(*+2%-H1:$6?1 6#-%-?+C%-B-R'M#$(+ 31#-%(%%$(#1@L(3G(%0

1. S1=3/6%%2-B- :4$$M31@(8(#$6 81:$1#.

2. E$3-86%%?($6?($1C%1@+>+L1C %1@?-G6/62 G-:/+GD43(%-H1:$6?1 $(HH 6/6?6%$+3

3. S:$(%-3/6%%=4?-3 3L(M?-G+/H - G1%1$(#-?</6#:4 $6@%+C%1-R+3

4. !6$(/0%(8-L8-R#(-#86?1@<8-6- #$%1@+U6%0

5. ^%(/+L<8-6#$%1@+U6%0<8(#$1- C%(<8-R(*+=$(3<8-3(GD6%%=

W68U6,P- <-$8+R%L8-R1$1*6 31- 3C1$1<1$(%%=G-*+/0%-:$+:$3-86%%=+% >-8?(*+2%-H1:$6?1, P- <8-@-G1$0G6#+ /0#(6$(<+3<-#(L(%1@%(81:. 1.

\1:.1. W812%=$$3+U6%%<8- %6-R@+G%:$$86%%¥E