Water Removal from Pan

The objective of this research was to test whether or not water can be removed from the wall cavity under different pressures, with and without insulation and air cooler.

The factors in the experiment were as follows:
- **Pressure Readings** (three levels): 30, 20, 10 psi
- **Insulation** (two levels): Yes/No
- **Air cooler** (two levels): Yes/No

A controlled amount of water (285 ± 5 g) was placed inside a holding pan and the following measurements were recorded:

- Initial weight of wall (no water)
- Weight of pan + water
- Weight of wall + water
  - Hourly measurements of wall + water (1 – 4 hr)
- Final weight of pan + water

**Research Questions**

Looking at the amount of water lost hourly as well as total (pan and wall):

1. Is there a difference in water removal with and without the air cooler at respective pressure readings?
   - a. With and without insulation?
   - b. Are there hourly differences?

2. Is there a difference in the total amount of water removed from the pan versus the total amount of water removed from the wall?
   - a. With and without insulation
   - b. With and without air cooler

I am more interested in showing the total loss from the pan versus the total loss from the wall.
Comments

The response variable is Pan_final_gr.

The authors cleverly recorded the initial wall and initial pan weights, which can be used as covariates in analysis of variance to test the effects of factors on water removal.

A linear model can be fit to the response variable to test the following hypotheses:

- Pressure differences are not different for water removal (H0:μ1=μ2=μ3=0)
- Insulation does not affect water removal (H0:μ1=μ2=0)
- Air Cooler does not affect water removal (H0:μ1=μ2=0)

The model is

\[ y_{ijkl} = \mu + \beta X + I_j + P_i + A_k + PI_{ij} + PA_{jk} + IA_{ijk} + e_{ijkl} \]

- \( y_{ijkl} \) is the 4th observation of the 4th pressure, 4th insulation and 4th air cooler;
- \( \mu \) is the overall mean;
- \( X \) is the covariate (initial pan weight);
- \( \beta \) is the coefficient of the covariate;
- \( P_i \) is the 4th pressure effect (i=1,2,3), E(P) = 0;
- \( I_j \) is the 4th Insulation effect (j=1,2), E(I) = 0;
- \( A_k \) is the 4th Air cooler effect (k=1,2), E(A)= 0;
- \( PI_{ij} \) is 4th pressure by 4th insulation interaction;
- \( PA_{jk} \) is 4th pressure by 4th air cooler interaction;
- \( IA_{ijk} \) is 4th insulation by 4th air cooler interaction;
- \( e_{ij} \) is random error associated with 4th observation of the 4th pressure, 4th insulation and 4th air cooler with the expectations of \( \sim NID (0, \sigma^2) \).

SAS GLM procedure (SAS 9.2) can be used to test the hypotheses outlined above.

ods graphics on;
proc glm data=pan ;
class Pressure Insulation Aircooler ;
model pan_final_gr = pan_in_gr pressure Insulation aircooler pressure*insulation pressure*AirCooler insulation*aircooler ;
means pressure Insulation aircooler /tukey ;
means pressure*Insulation pressure*AirCooler insulation*aircooler/tukey ;
run;
ods graphics off;

The output from is given below:
The GLM Procedure

Class Level Information

Class          Levels     Values
Pressure       3          PSI10 PSI20 PSI30
Insulation     2          Insulation NoInsulation
AirCooler      2          AirCooler NoAircooler

Number of Observations Read      144
Number of Observations Used      144

Dependent Variable: Pan_final_gr

Sum of
Source                     DF     Squares  Mean Square  F Value  Pr > F
Model                      10     53985.66435  5398.56643  102.46  <.0001
Error                      133     70.07.40565  52.68726
Corrected Total            143     60993.07000

R-Square     Coeff Var  Root MSE  Pan_final_gr Mean
0.885111     2.698916  7.258599  268.9450

Source                     DF     Type I SS  Mean Square  F Value  Pr > F
Pressure                   2      5829.22320  2914.61160  55.32  <.0001
Insulation                 1      43538.99560  43538.99560  826.37  <.0001
AirCooler                  1      91.01160      91.01160      1.73  0.1910
Pressure*Insulation        2      3138.58320  1569.29160  29.79  <.0001
Pressure*AirCooler         2      421.71387   210.85693     4.00  0.0205
Insulation*AirCooler       1      953.16271    953.16271     18.09  <.0001
Pan_in_gr                  1      12.97417     12.97417     0.25  0.6205

The F tests in above output show that the main effects of Pressure and Insulation are highly significant, while the effect of AirCooler was not. All two-way interactions were also significant. Thus, although Air cooler main effect is not significant, it should be kept in the model to have hierarchical models. The Pressure*Insulation interaction effect is highly significant with a Pr value of <0.0001.

The next step is look at the multiple range to see which levels of a factor are different from each other and how the levels interacts with other factors.
Tukey's Studentized Range (HSD) Test for Pan_final_gr

NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha 0.05
Error Degrees of Freedom 133
Error Mean Square 52.68726
Critical Value of Studentized Range 3.35203
Minimum Significant Difference 3.5119

Means with the same letter are not significantly different.

Tukey Grouping | Mean   | N   | Pressure
---             | ------ | --- | --------
A               | 277.300| 48  | PSI10    
B               | 267.660| 48  | PSI20    
C               | 261.875| 48  | PSI30    

The Tukey grouping shows that under PSI30, water removal from the pan is the most efficient, followed by PSI20 and PSI10.

Tukey's Studentized Range (HSD) Test for Pan_final_gr

NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha 0.05
Error Degrees of Freedom 133
Error Mean Square 52.68726
Critical Value of Studentized Range 2.79726
Minimum Significant Difference 2.3929

Means with the same letter are not significantly different.

Tukey Grouping | Mean          | N   | Insulation
---            | -----         | --- | --------
A              | 286.333       | 72  | Insulation
B              | **251.557**   | 72  | NoInsulation

Having no insulation is more efficient in water removal than with insulation.
Tukey's Studentized Range (HSD) Test for Pan_final_gr

NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha                                   0.05
Error Degrees of Freedom                 133
Error Mean Square                   52.68726
Critical Value of Studentized Range  2.79726
Minimum Significant Difference        2.3929

Means with the same letter are not significantly different.

Tukey Grouping          Mean      N    AirCooler
A       269.740     72    NoAircooler
A       268.150     72    AirCooler

Multiple range tests with interactions

<table>
<thead>
<tr>
<th>Level of Pressure</th>
<th>Level of Insulation</th>
<th>N</th>
<th>--------Pan_final_gr--------</th>
<th>--------Pan_in_gr--------</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSI10</td>
<td>Insulation</td>
<td>24</td>
<td>288.833333</td>
<td>297.691667</td>
</tr>
<tr>
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<td>NoInsulation</td>
<td>24</td>
<td>265.766667</td>
<td>297.833333</td>
</tr>
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<td>24</td>
<td>285.333333</td>
<td>296.333333</td>
</tr>
<tr>
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<td>NoInsulation</td>
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<td>249.986667</td>
<td>298.186667</td>
</tr>
<tr>
<td>PSI30</td>
<td>Insulation</td>
<td>24</td>
<td>284.833333</td>
<td>298.333333</td>
</tr>
<tr>
<td>PSI30</td>
<td>NoInsulation</td>
<td>24</td>
<td>238.916667</td>
<td>298.616667</td>
</tr>
</tbody>
</table>

Since interactions are significant, comparing different pressures with Insulation and without insulation makes more sense than comparing the main effects of pressure. The above means shows that when pressure is combined with insulation, the best results (water removal) can be obtained by having PSI30+No Insulation. The pan weight with and without insulation under PSI30 is 284.8 and 238.9, respectively. This is about 46 gram difference. On the other hand the main effect of PSI30 was only 261.87 g.

<table>
<thead>
<tr>
<th>Level of Pressure</th>
<th>Level of AirCooler</th>
<th>N</th>
<th>--------Pan_final_gr--------</th>
<th>--------Pan_in_gr--------</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSI10</td>
<td>AirCooler</td>
<td>24</td>
<td>274.410000</td>
<td>298.191667</td>
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<tr>
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<td>NoAircooler</td>
<td>24</td>
<td>280.500000</td>
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<td>AirCooler</td>
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<td>267.833333</td>
<td>296.833333</td>
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<tr>
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<td>NoAircooler</td>
<td>24</td>
<td>267.486667</td>
<td>297.686667</td>
</tr>
<tr>
<td>PSI30</td>
<td>AirCooler</td>
<td>24</td>
<td>262.516667</td>
<td>298.616667</td>
</tr>
<tr>
<td>PSI30</td>
<td>NoAircooler</td>
<td>24</td>
<td>261.233333</td>
<td>298.333333</td>
</tr>
</tbody>
</table>

In above output, having air cooler or not is significant only when the air pressure is PSI10. If the pressure is low (PSI10) then having air cooler will have a significant impact on water emoval. However, air cooler does not have an effect when the pressure is greater (PSI20 and PSI30).
Comparing insulation levels with and without Air Cooler shows significant interactions. When there is no insulation, Air Cooler is more efficient in water removal. The difference between Yes and No air cooler when there was no insulation was 254.92 - 248.19 = 6.735 g.

Using charts to examine the main effects and their interactions
The interaction of pressure and insulation

The relative difference between having insulation and not having insulation is not the same across different pressures. The effect of insulation is the greatest when the pressure is PSI30. If a wall is insulated, the pressure should be greater than PSI10 (e.g., PSI20 and PSI30) in order to see a significant water removal. However, we did not see significant difference between PSI20 and PSI30 when the wall is insulated.