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UV Flexo Ink Composition and Surface Treatment Effects on Adhesion to Flexible Packaging

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Propositions

- **UV flexo inks becoming increasingly popular in flexible packaging and shrink sleeve applications, traditional markets for flexographic inks.**
- **Improvements in UV flexo inks such as print quality, low ink maintenance requirements, no solvents, high press stability, and in-line finishing contribute to decisions to switch to UV flexo system.**
- **Recent UV flexo ink systems improve efficiency and production speeds to > 250 meters/minute.**

Propositions

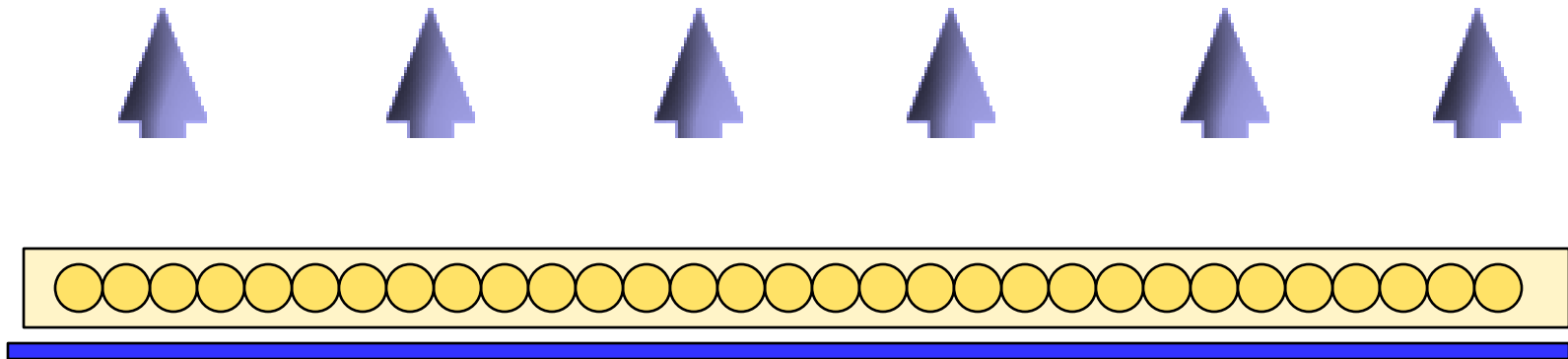
- Resin selection, amount of ink applied, substrate absorbency, UV curing conditions and print speed can propagate episodes of erratic adhesion.
- Primers can be used but not always successful, increase cost to the convertor.
- Presentation will detail the effects of corona, flame or atmospheric plasma surface treatments on the adhesion of UV flexo inks to flexible packaging films.

Propositions

- Properties of cured UV inks/coatings improve abrasion resistance compared to solvent- and water-based inks.
- UV inks perform well with UV and EB coatings used in flexible packaging structures.
- Being applied internally and externally with high performance packaging structures.
- Provide significant step toward sustainability by eliminating/reducing the emissions of VOCs and CO₂.

Propositions

- Drying of conventional ink film occurs when ink solids (resins, additives, pigment, etc.) coalesce into a film on the substrate surface accompanied by evaporation of volatiles and/or penetration into the base substrate.



- Trapping these interfaces, particularly with water-based inks, can trap volatile amines which can exist as salts, interfering with interface-to-substrate bonding. Not an issue w/ chemically converted UV/EB.

The Challenge

- Formulation of UV flexo inks with low viscosity, high color strength, high cure speeds and adhesion is a considerable challenge for ink formulators.
- To optimize anchorage of UV oligomer-monomer carriers to the substrate, surface modification by corona, flame or atmospheric plasma provide efficient surface roughening and functionalizing effects.
- Study seeks to understand synergistic interactions between different surface modification techniques and different oligomer types in UV flexo ink formulations, and impact of synergies on ink adhesion to unprimed flexible polymer-based surfaces.

Experimental - Oligomers Evaluated

Products	Description	Functionality	Viscosity (cP @ 25C)
EBECRYL® 83	Amine Modified Polyester Acrylate	3.5	515
EBECRYL 3702	Fatty Acid Modified Epoxy Acrylate	2	495,000
EBECRYL 4883	Aliphatic Urethane Acrylate	2	161,000
EBECRYL 860	Epoxidized Oil Acrylate	4	26,500
EBECRYL 5801	Polyester Acrylate Bioligomer	3	6,000
EBECRYL 450	Fatty Acid Modified Polyester Acrylate	6	8,200
EBECRYL 3703	Amine Modified Epoxy Acrylate	2	320,000
EBECRYL 4827	Aromatic Urethane Acrylate	2	238,000
EBECRYL 3720	Bisphenol-A Epoxy Acrylate	2	750,000

All monomers , oligomers and photoinitiator supplied by Cytec Industries (Smyrna, GA)

Experimental – Surface Treatments Evaluated

- **Universal corona discharge - dual dielectric corona system, high voltage/low frequency transformer and power supply.**
- **Flame plasma discharge - high velocity, CNC fabricated port burner, water cooled lateral ports, chilled treater roll, electronic combustion/gas mixing controls, and integrated electronic oxygen analyzer.**
- **Atmospheric plasma discharge – proprietary plasma dielectrics, gas chemistries electronically controlled.**

Experimental - Surface Modification Trial Protocol

Material	Corona	Flame	Plasma		Power Density (W/ft ² /min.)	Initial mN/m	Final mN/m
			Carrier %	Reactive %			
PLA	CU				1	35	42
PLA	CU				1	35	42
PLA		FM			1100 lpm/1200fpm	35	42
PLA		FM			1100 lpm/1200fpm	35	42
PLA			Nitrogen/95	CO ₂ / 5	1	35	42
PLA			Nitrogen/95	CO ₂ / 5	1	35	42
PET	CU				1	36	44
PET	CU				1	36	44
PET		FM			1100 lpm/1200fpm	36	44
PET		FM			1100 lpm/1200fpm	36	44
PET			Nitrogen/95	CO ₂ / 5	1	36	44
PET			Nitrogen/95	CO ₂ / 5	1	36	44
Met. OPP	CU				2.6	30	44
Met. OPP	CU				2.6	30	44
Met. OPP		FM			1300 lpm / 500fpm	30	44
Met. OPP		FM			1300 lpm / 500fpm	30	44
Met. OPP			Nitrogen/95	CO ₂ / 5	2.6	30	44
Met. OPP			Nitrogen/95	CO ₂ / 5	2.6	30	44

All films and surface treatments supplied by Enercon Industries (Menomonee Falls, WI)

Experimental – Surface Treatments Evaluated

- Universal corona discharge technology chosen because of its homogeneous discharge, offering a higher potential for surface adhesion.
- Flame plasma technology utilized high velocity port burner with electronic mass flow control of air and natural gas inputs at a 10:1 ratio, respectively, electronic oxygen content control.
- Atmospheric plasma treatment ionized mixture of N₂ and CO₂ using electronic mass flow controls at high frequency.



Experimental – Uncoated Films Evaluated

Material	Supplier
Biaxially oriented PLA 4042D, 20 microns	NatureWorks®
AET MT metalized, BOPP film, 18 microns	AET films
Uncoated PET	Teijin DuPont Films Japan Ltd.

Experimental – Testing Protocol

- Bench-evaluations completed at Cytec using hand-held flexographic print instruments equipped with 360 ls anilox roll and metal doctor blade.
- Bench-produced prints cured in Fusion Aetek UV unit at 150 fpm using 400W/inch mercury lamps in air. Exposure was 120 mJ/cm².
- Starting formulations tested on Aquaflex LC-1002 printing press using same films as in bench-testing.
- Press evaluation at 150 – 350 fpm.
- Inks printed with a 700 line screen/2.43 BCM anilox roll and cured with Fusion Aetek UltraPak 400W/inch lamps.

Experimental – Testing Protocol

- Adhesion tested after ink cure using 3M 610 Scotch Tape® on unscored print surface.
- Prints from bench testing rated for ink adhesion using a relative scale of 1 – 5, with 1 = poor and 5 = excellent.
- Press trial prints evaluated for adhesion by visually assessing quantity of ink remaining on substrate after tape removal.
- Percent value assigned to amount of ink remaining, with no ink removal = 100% adhesion and complete ink removal = 0% adhesion.

Experimental – Diluents and Monomers

Evaluation of reactive diluents and monomers

Monomer		Reactivity	Adhesion	Flexibility
Isobornyl Acrylate	IBOA	1	4	5
Octyl/Decyl Acrylate	ODA	1	3	5
Tripropylene Glycol Diacrylate	TRPGDA	3	3	4
1,6-Hexanediol Diacrylate	HDODA	3	5	3
Trimethylpropane Triacrylate	TMPTA	5	4	3
Propoxylated Glycerol Triacrylate	GPTA	5	2	2
Trimethylolpropane Ethoxy Triacrylate	TMPEOTA	4	2	2

Reactivity, adhesion and flexibility were assessed on a scale of 1-5, 1=poor and 5=excellent

Experimental – Diluents and Monomers

- From results, monomers chosen for further evaluation in UV inks for press trial were Trimethylolpropane triacrylate (TMPTA) and Tripropylene glycol diacrylate (TRPGDA)
- Used in 1:1 ratio to combine the reactivity of TMPTA and the flexibility offered by TRPGDA.

Experimental – Defining the Oligomer

- Oligomers and monomers assessed for basic properties on metalized OPP, PET and PLA film substrates.
- Samples of each of the three substrates were treated with the three types of surface treatment
- Selected oligomers diluted with Trimethylolpropane Triacrylate (TMPTA) to viscosity of 500 mPa.s @ 25°C.
- After dilution, 10% Additol DX liquid photoinitiator blend added to each sample.
- Oligomer/monomer/PI blends printed on substrate samples and each print assessed for tape adhesion.

Bench evaluation to define oligomers for the press trials: adhesion results

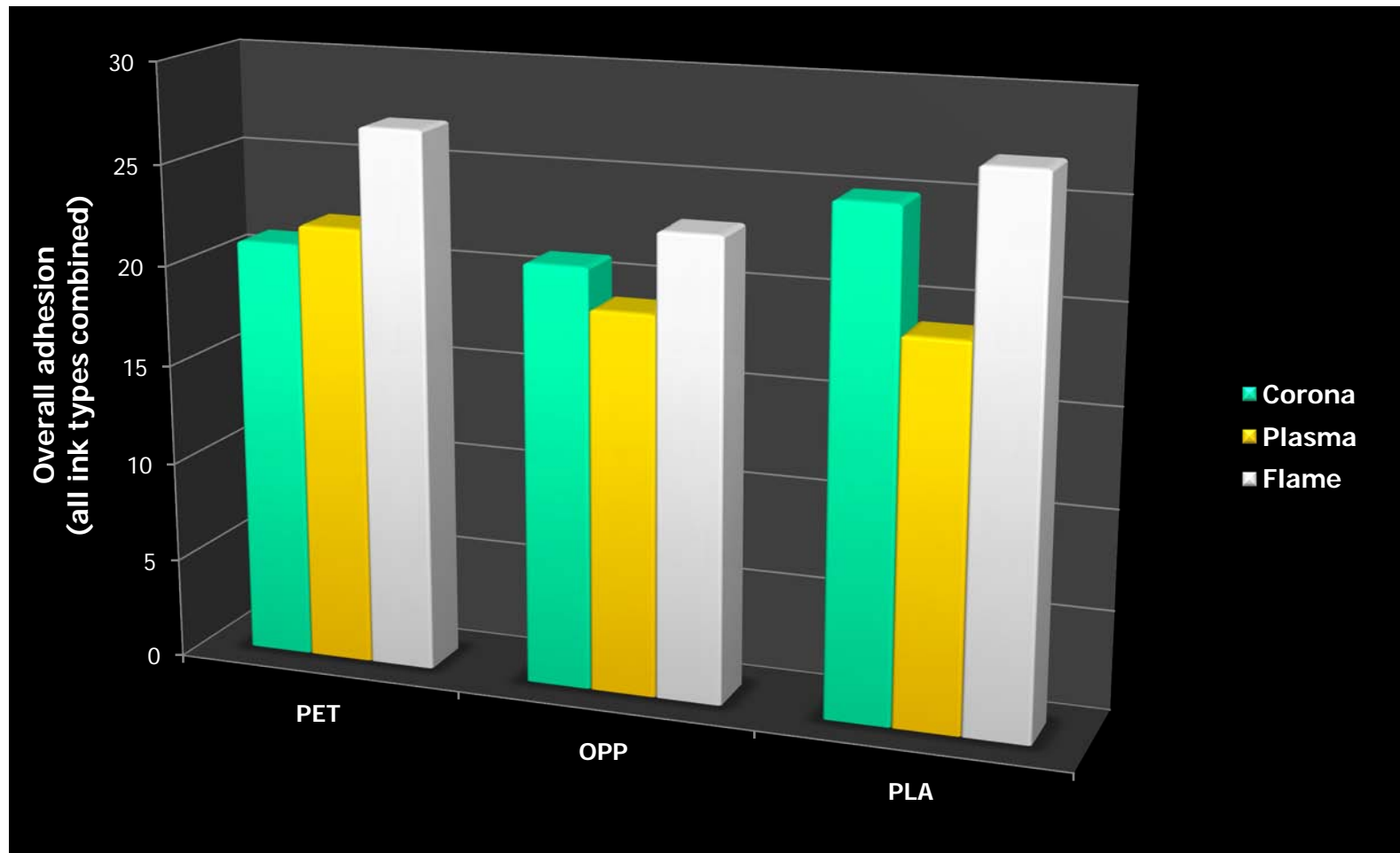
	PET			Metalized OPP			PLA		
	Corona	Plasma	Flame	Corona	Plasma	Flame	Corona	Plasma	Flame
Amine modified polyester acrylate	1	1	2	2	1	2	3	2	3
Fatty Acid modified epoxy acrylate	2	2	3	1	1	2	2	2	2
Acrylate Aliphatic Urethane Acrylate	3	3	3	3	2	3	2	2	3
Epoxidized Oil Acrylate	2	3	4	2	2	3	4	4	5
Polyester Acrylate Bioligomer	4	3	5	3	3	4	4	2	4
Fatty Acid Modified Polyester Acrylate	5	4	5	4	3	4	4	3	4
Amine Modified Epoxy Acrylate	2	3	2	3	2	1	2	2	1
Aromatic Urethane Acrylate	1	2	1	2	3	3	2	1	1
Bisphenol-A Epoxy Acrylate	1	1	2	1	2	1	2	1	1
TOTAL	21	22	27	21	19	23	25	19	27

Adhesion was assessed on a scale of 1-5, 1=poor and 5=excellent

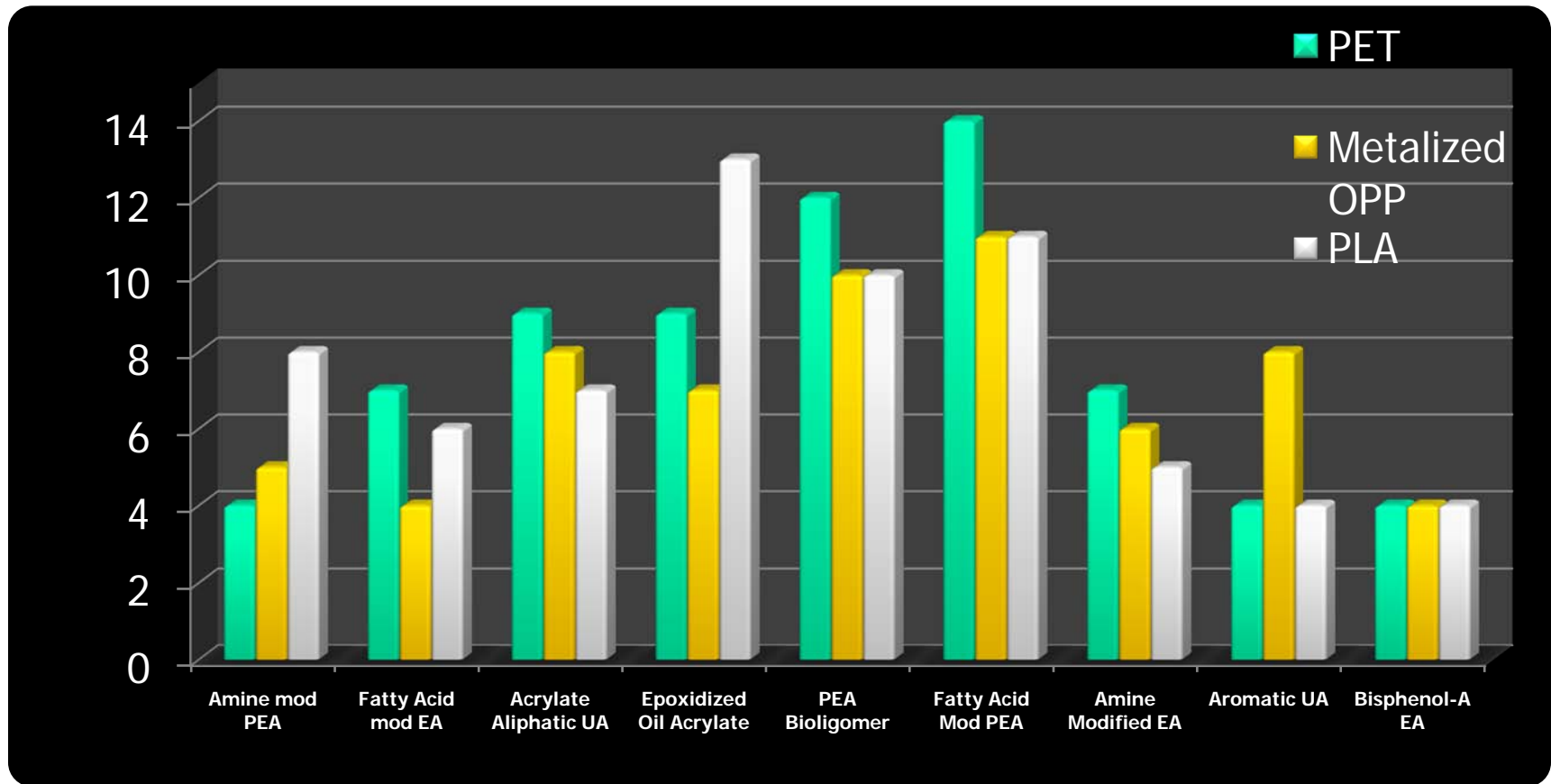
Experimental – Preliminary Evaluations

- Differences identified in adhesion; generally increased adhesion to the corona- or flame-treated films compared to the plasma-treated films.
- Surface energy, and ultimately ink adhesion, of flame-treated substrates deteriorated within 2-3 days.
- Plasma- and corona-treated films retained surface energy for a significantly longer period (up to 10 days)
- Ink adhesion maintained on corona-treated film as surface energy deteriorated; ink adhesion significantly reduced on the plasma-treated substrates.

Overall adhesion by film and treatment types



Overall adhesion by film and oligomer types



Experimental – Preliminary Evaluations

- Analysis of adhesion based on film and oligomer types indicates ink composition, specifically oligomer selection, significantly affects adhesion.
- Review was used, in part, to help select final ink composition.
- Based on these results, further evaluations performed using top performing oligomer groups; fatty acid modified polyester acrylate and polyester acrylate bioligomer.

Ink starting point formulation

Pigment	18%
Oligomer	35%
Monomer(s)	37%
Photoinitiator	10%

Results – Final Formulations

- Final two ink formulations identified by bench-evaluation tested at Cytec on Aquaflex LC-1002 printing press using corona-treated OPP and PLA films.
- Additional PET film was unavailable at the time of testing.
- Treatment types used with OPP and PLA films also evaluated at 150 fpm & 350 fpm in Fusion Aetek UV unit.

Results – Final Formulations

- At low line speeds (150 fpm), acceptable adhesion was obtained with both inks on both films and with all treatment types.
- As the line speed increased, adhesion to corona-treated films maintained with ink based on fatty acid modified polyester acrylate, but reduced with polyester acrylate bioligomer.
- Might be related to difference in reactivity between the two oligomers.
- At higher line speed, adhesion to plasma-treated films appeared to be less than adhesion to the other two types of surface treatments (evidence of surface organics adhesion with corona and flame)

Adhesion results with final ink formulations

		OPP			PLA		
		Flame	Plasma	Corona	Flame	Plasma	Corona
Polyester Acrylate Bioligomer	150 fpm	80%	80%	95%	85%	75%	95%
	350 fpm	50%	50%	65%	25%	25%	50%
Fatty Acid Modified Polyester	150 fpm	90%	90%	95%	90%	90%	95%
	350 fpm	80%	75%	85%	90%	70%	90%

- *Adhesion was visually assessed.*
- *The % reported is the approximate ink coverage remaining in the tape area after the tape is removed.*

Results – Final Formulations

- Final ink formulations tested did not contain modifying resins and/or additives commonly used in ink formulating to increase adhesion or tape release.



Conclusions

1

Oligomer and monomer selection must be completed to match the type of film and film surface treatment used to prepare the substrate for printing.

2

Differences in ink adhesion can be easily identified when the ink is printed on the same base film finished with different surface treatments.

3

At higher line speed, adhesion to the plasma-treated film is less than adhesion to the corona- and flame-treated samples of the same film.

Conclusions

4

As the treated substrates age, ink adhesion to flame-treated film deteriorates rapidly within a few days while adhesion to the plasma- and corona-treated films remain for a longer period.

5

Fatty Acid Modified Polyester Acrylate-based ink displayed better adhesion than the Polyester Acrylate Bioligomer-based ink, especially at increased press speed.

6

Therefore, if “green” property is desired in both film (e.g. PLA) and ink, optimization must be completed with ink composition to find the best balance of properties.

Conclusions

7

Levels and types of monomers commonly used to improve ink adhesion, e.g. HDODA, must be evaluated and optimized to obtain best ink adhesion while avoiding damage to the flexographic printing plate.

Thank you!

PRESENTED BY

Rory Wolf

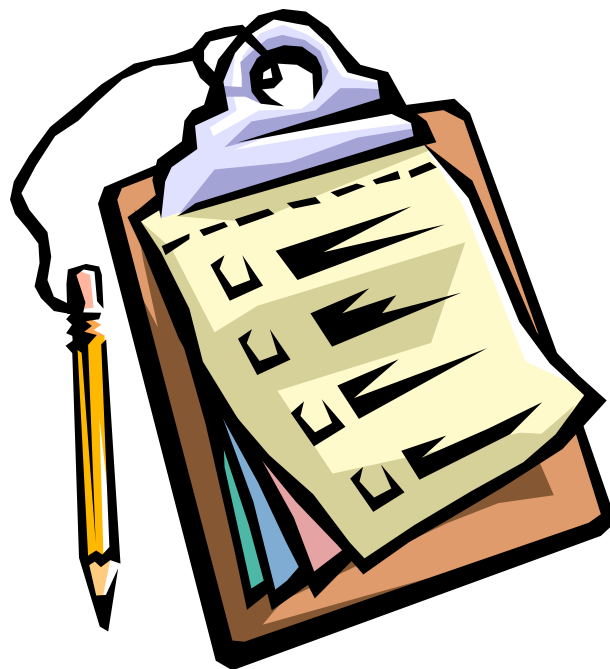
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